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INDUSTRIAL FOG, CLOUD, AND PRECIPITATION
AT VERY LOW TEMPERATURES

by

© CHAN PARK

A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "Industrial Fog, Cloud, and Precipitation at Very Low Temperatures", submitted by Chan Park in partial fulfilment of the requirements for the degree of Master of Science in Meteorology.

ABSTRACT

The body of information in this thesis is directed to engineers who are involved in the environmental aspects of northern development.

Fog, cloud, and precipitation caused by the petrochemical industries of Edmonton, Canada, were studied during the coldest days of four winters. Typical morning temperatures were between -15 and -40°C. The investigation includes a comprehensive heat and vapor emission inventory, field studies of local and microscale cloud physics, and observations of plume cloud dispersal and precipitation formation.

Emphasis is on the cloud microphysics of snow which falls from cooling tower plumes. Since this snow is nucleated by cooling tower drift droplets, its development is different than that of natural snowfall. Measured snowfall rates are small compared with those reported during warmer weather when cooling tower emissions can trigger impending natural snowfall.

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CHAPTER 1

INTRODUCTION

Much of the literature on weather modification by urban-industrial environments in Arctic and Subarctic regions has to do with ice or water fogs. These fog studies cover aspects such as dependence on heat and moisture emission rates, influence of aerosols acting as condensation nuclei or ice nuclei, comparisons to natural fogs, and, finally, human problems associated with visibility reduction and pollution increases. The locations of these studies include: Fairbanks (Robinson et al., 1957; Weller, 1969; Benson, 1970; Ohtake, 1970), Alaska and the Yukon (Ives and Berry, 1974), the Mackenzie Valley (Csanady and Wigley, 1973), Edmonton (Robertson, 1955; Hage, 1972), northern airports (Lawford et al., 1974), and the oil sands plants in Alberta (Croft et al., 1976; Murray and Low, 1979). These studies have shown how mixing of hot, moist emissions with very cold air causes condensation and subsequent freezing of water droplets by the abundant suitable nuclei. Temperatures as low as $-52^{\circ}C$ in Fairbanks (Benson, 1970) and $-44^{\circ}C$ in Edmonton (Robertson, 1955) were studied.

This thesis reports on weather modification at the Strathcona County industrial area near Edmonton, Alberta on cold winter days when temperatures ranged from -15° to $-40^{\circ}C$. To now, little has been done in the field to study such a situation in spite of

the possible importance of such research to northward industrial development. Therefore, this study set out to develop an understanding of the general character of low temperature industrial clouds including fogs, plumes, precipitation and their associated cloud microphysics.

CHAPTER II

THE INDUSTRIAL AREA AND ITS VAPOR EMISSIONS

Edmonton ($53^{\circ}33'N$, $113^{\circ}30'W$, MSL 670 m) is the petroleum center of Canada. It is located on the North Saskatchewan River. The topography of the city and the location of the industrial area is shown in Figure 2.1. The topography rises by less than ten meters per kilometer throughout the city except near the river valley which is steep-sided with an average depth of about fifty meters and a width of one kilometer. The heavy industries are confined to an area of about thirty square kilometers at the eastern outskirts of the city. Figure 2.2 shows the approximate location of each industry. The major industries in this industrial area are a petrochemical complex (CELANESE), three oil refineries (GULF, IMPERIAL, TEXACO), metal fabrication (STELCO), plastic production (C.I.L.), fiberglas (FIBERGLAS), a natural-gas-fired electricity generating station (EDMONTON POWER), and petroleum coke processing (ALCAN).

A comprehensive cold-weather heat and moisture emission inventory of fifteen industrial companies was made by Charlton and Park (1979). The results are summarized in Figure 2.2 and Table 2.1. Figure 2.2 shows the location and total water vapor emissions of each industry surveyed; Table 2.1 reports the best estimates of heat and vapor emissions available for the winter of 1977-78. It

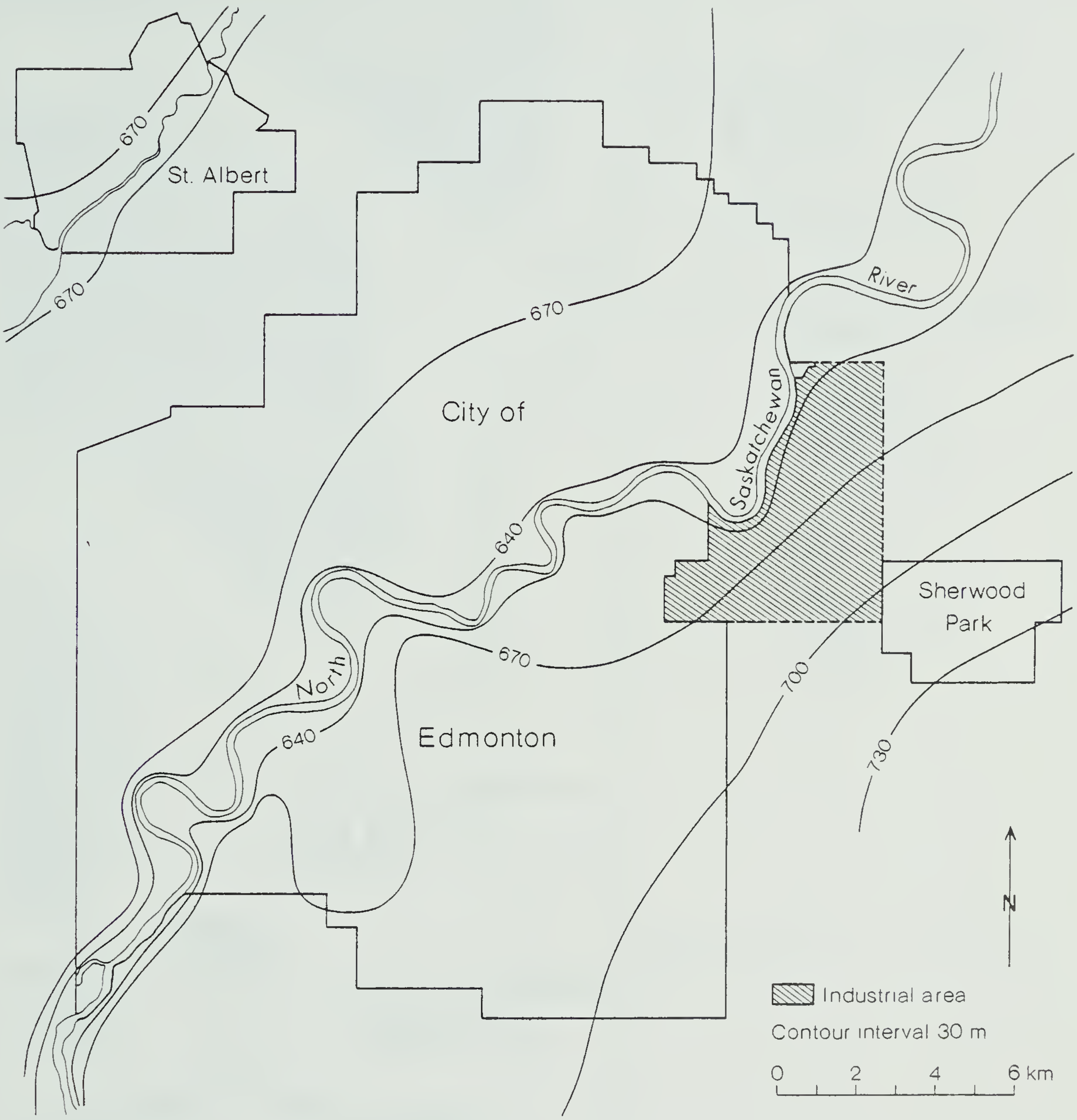


Figure 2.1 Edmonton: topography and industrial area.

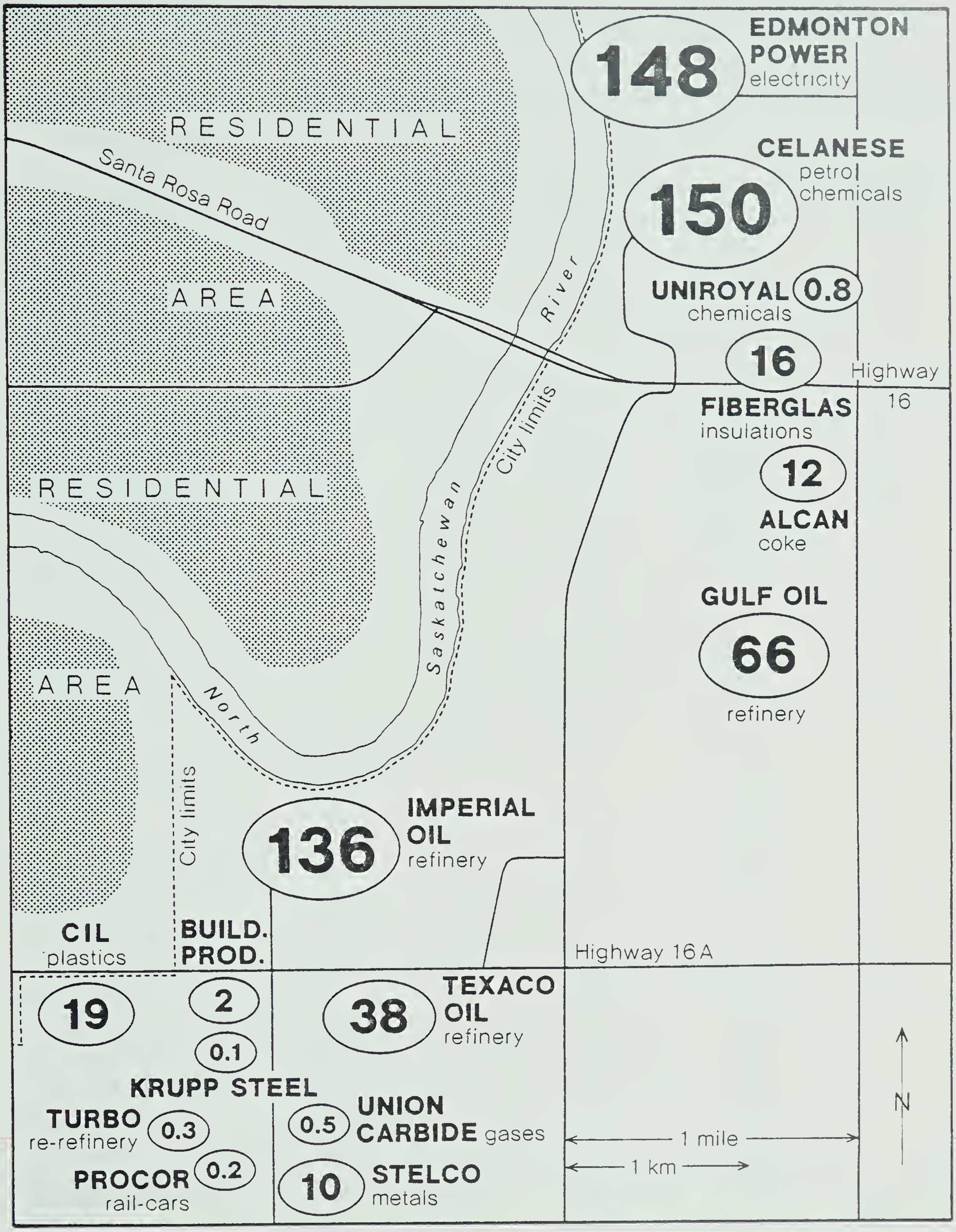


Figure 2.2 Strathcona industrial area showing major plants, and their water vapor emission rates (kg s^{-1}) for the winter of 1977-78.

Table 2.1. Emissions from Strathcona industrial area, as reported in survey.

Plant Name and (product)	Water vapor, kg/s^{-1} and (sensible heat, MW) Low[a]	Middle[a]	High[a]	Total	Fuel consumption MW
ALCAN (coke)	1 (20)	2 (25)	9 (15)	12 (60)	70
BUILDING PRODUCTS (building paper)	2 (11)	-- --	-- --	2 (11)	17
CIL (polyethylene resin)	4 (18)	4 (18)	11 (21)	19 (57)	98
CELANESE[b] (petrochemicals)	20 (120)	30 (80)	100 (200)	150 (400)	800
EDMONTON POWER (electricity)	106 (265)	0.2 (40)	42 (100)	148 (405)	1000
FIBERGLAS (insulation)	0.1 (1)	1 (2)	15 (10)	16 (13)	50
GULF OIL (refinery)	4 (92)	7 (47)	55 (124)	66 (263)	408
IMPERIAL OIL (refinery)	9 (160)	16 (88)	111 (313)	136 (561)	860
KRUPP, G.W.S. (structural steel)	0.1 (2)	-- --	-- --	0.1 (2)	2
PROCOR (railway car repair)	0.2 (6)	-- --	-- --	0.2 (6)	6
STELCO (steel products)	3.5 (8)	6.5 (13)	-- --	10 (21)	41
TEXACO OIL (refinery)	3 (26)	6 (13)	29 (68)	38 (107)	190
TURBO OIL (re-refinery)	0.3 (3)	-- --	-- --	0.3 (3)	3
UNION CARBIDE[b] (gases)	0.5 (3)	-- --	-- --	0.5 (3)	5
UNIROYAL (chemicals)	0.3 (3)	0.5 (1)	-- --	0.8 (4)	7
TOTALS	154 (738)	73 (327)	372 (851)	599 (1916)	3557
EDMONTON CITY (at -35°C)	258 (6400)	? ?	-- --	258 (6400)	6400
TWO OIL SANDS PLANTS (at -35°C)	137 (492)	216 (1342)	112 (349)	465 (2184)	3144

[a]Division into three levels is partly based on visual observations

[b]Estimates based on incomplete data

reports the emissions divided into three different groups: low, middle, and high, on the basis of levels at which the heat and moisture emissions mix into the air. This division, according to altitude of dispersal, is based partly on subsequent field observations and partly on consideration of source characteristics, and it can be summarized as follows. The low-level emission sources are likely to form general ground-based plant-site fogs. Of the plants surveyed, only Edmonton Power releases waste heat in the form of hot water into the river. Middle level emissions contribute to inter-plant fog and cloud formation at typical heights of 50 to 100 meters. A number of small stacks on the plant roofs, and small single-cell cooling towers fall into this category. Finally, high level emissions are attributed to large stacks and several mechanical-draft cooling towers. These sources form plume clouds which rise to between 100 and 300 m during cold days with light winds.

The last column in Table 2.1 gives average fuel consumption rates at each plant. The area's total fuel consumption rate is 3557 MW. Edmonton Power exports 350 MW of electrical power from its 1000 MW fuel consumption. Table 2.1 also includes sensible heat and water vapor emissions for Edmonton City (population 500,000), based on ice fog studies (Hage, 1972) and for two oil sands plants in Northern Alberta (Croft et al., 1976; SNC, 1977). Table 2.1 indicates that both total fuel consumption and total vapor emission rates are comparable in magnitude for the three places, i.e., the city, the industrial area, and the oil sands plants. One difference is as follows: Although the heat and

moisture sources in the city are dominated by low-level emission sources, the depth of low-temperature fog in the city is often seen to vary with the height of the buildings which measure up to about 110 m. Therefore, in terms of Table 2.1, the city would have some middle-level emissions. This explains why the question marks have been placed in the city's spaces for middle-level emission sources.

Since this study also stresses the plumes and precipitation formed by the large cooling towers, the high-level emissions given in Table 2.1 were broken down into those from cooling towers and those from high stacks. Table 2.2 shows the results of that breakdown. Plate 2.1 shows the plumes from most of these major vapor sources as seen on a cool day ($T = -8^{\circ}C$).

Table 2.2. High-level emission sources on cold days.

Plant Name	Cooling Towers		High Stacks	
	Heat (MW)	Vapor (kg/s)	Heat (MW)	Vapor (kg/s)
C.I.L.	21	11	--	--
CELANESE	150	75	50	25
GULF REFINERY	80	50	44	5
IMPERIAL REFINERY	225	100	88	11
TEXACO REFINERY	50	25	18	4
TOTALS	526	261	200	45

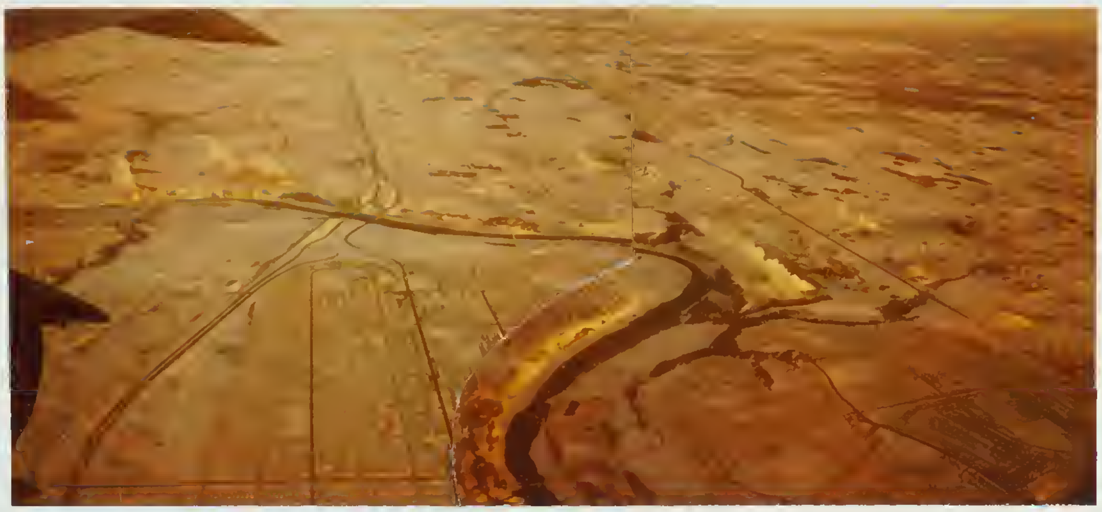


Plate 2.1. Aerial view of the Strathcona County industrial area looking eastward. $T = -8^{\circ}C$. Plumes seen from left to right are Edmonton Power (large), Celanese (two large), Fiberglas (medium), Alcan (small), Gulf (large), Imperial (very large in foreground), Texaco (large), GWS (small), Stelco (small), and CIL (large in right foreground).

CHAPTER III

CONDUCT OF THE FIELD EXPERIMENTS AND SOURCES OF WEATHER DATA

This chapter first describes how field observations of plume clouds, fogs, and precipitation were conducted during the winters of 1977-78, 1978-79, and 1979-80. Finally, sources of supportive weather data are discussed. For simplicity, each activity is explained in a subsection.

3.1 Appropriate days

Most field trips were made during clear and cold mornings when humidities are at or near ice saturation. Such conditions isolate and accentuate the effects of the industrial heat and moisture sources. Preference was given to days with very low temperatures (about -30°C or colder) but days with very low wind speeds and temperatures below about -15°C also proved to be worthy of field trips. Appendix F gives weather data for dates studied.

3.2 Visual observations

Visual observations were documented using color print film in 35 mm automatic iris cameras and by sketching observations

on special base maps of the industrial and surrounding area. Most field trips covered several tens of kilometers in an automobile equipped with an adequate heater to prevent cameras, films and fingers from freezing when outdoor temperatures ranged between -20 and -40°C. Extensive travel was frequently necessary to get photographs at right-angles to the plumes or to separate fog from plumes in the pictures. Visual observations for five typical days are discussed in detail in Chapter IV and displayed in Figures 4.1 through 4.5 which show summaries of the visual observations in map form.

3.3 Precipitation rates

The main sources of man-made precipitation proved to be the large mechanical draft cooling towers. Some fine snow particles also fell from large stacks and fog. Precipitation was measured by placing 0.65 m^2 cardboard trays downwind of the cooling towers. These trays were exposed for periods ranging from ten minutes to overnight depending on the observed snowfall intensity and plume persistence but exposure times were typically a couple of hours. A total of 43 snow samples were collected and stored in plastic bottles for later weighing to calculate precipitation rates.

3.4 Precipitation microphysics

Precipitation measurements were accompanied by observations of the sizes and shapes of the falling ice and snow particles. Using a common film inspection lens, particles ranging from a few

tens of micrometers to a few millimeters were routinely documented.

To document even finer details of the falling particles, plastic replicas of the particles were made for later laboratory analysis by using the following technique. A bottle of chilled 0.5 to 1 percent solution of Formvar plastic in 1,2-dichloroethane was kept available. In the field, a 2.5 x 7.5 cm glass slide was dipped into the solution and exposed to the falling particles for two minutes or so. As described by Schaeffer (1964), Strong (1966), and Mason (1971), the solution evaporates leaving permanent plastic replicas of the original particles. The snow replicas could be made very accurate by keeping the slides and solution at field temperatures for about an hour before and after exposure, thus avoiding "blushing" or "blooming" problems. Microscopic observations of the replicas revealed much about the physical processes which lead to precipitation formation in the plume clouds. Replicas were made on a total of 16 days, but they were sometimes not accompanied by tray samples of snowfall.

It is ideal to make several replicas and get tray samples along the length of a precipitating plume since these observations could show how the particle sizes and precipitation vary downwind of the moisture sources. Unfortunately, it was frequently difficult to gain access to such points or to see the plumes through the prevailing fogs. In spite of these sampling constraints, the replicas revealed good information about the cloud microphysics which is covered in Chapter V. For comparison sake, replicas were also made of natural snow.

3.5 Sources of weather data

Although weather conditions were checked visually before and after the field observations, weather reports from nearby stations and other sites are necessary to ascertain if the observed phenomena were caused by industrial sources, urban sources or natural clouds.

Stations from which hourly surface weather data (aviation observations) are available are Edmonton Municipal Airport (10 km WNW), Namao Military Airport (15 km NNW), and Edmonton International Airport (25 km SSW). These were used to compare temperature, precipitation, and cloudiness in the city and rural areas to conditions observed in the industrial area.

Two sources of vertical soundings were also available. Minisonde ascents were frequently sent up from Ellerslie (15 km SW) by Alberta Environment on weekday mornings to give vertical temperature and wind profiles. Radiosonde ascents are made from Stony Plain (50 km W) by the Atmospheric Environment Service at 0500 and 1700 LST every day to give vertical temperature, humidity and wind profiles.

Additional weather data includes temperature at 9 and 91 m and wind at 91 m from the CBC tower (8 km SE), plantside winds recorded at the Gulf refinery and plantside temperatures from Celanese.

Data from the above sources for the five days discussed in Chapter IV are tabulated in Appendices A through E.

CHAPTER IV

RESULTS OF THE FIELD STUDIES

This chapter describes in detail the meteorological observations made on five out of thirty-six days when field studies were conducted. Table 4.1 gives introductory information about the five case studies. Figures 4.1 through 4.5 are maps for each of the five days showing routes travelled, points where photographs or precipitation samples were taken, and the extent of plume and fog. Detailed tabulations of meteorological data for the five days are included in Appendices A through E.

To summarize all thirty-six days of field studies, this chapter ends with a description of the Strathcona industrial area in five degree intervals of temperature.

4.1 Case 1 - December 9, 1977

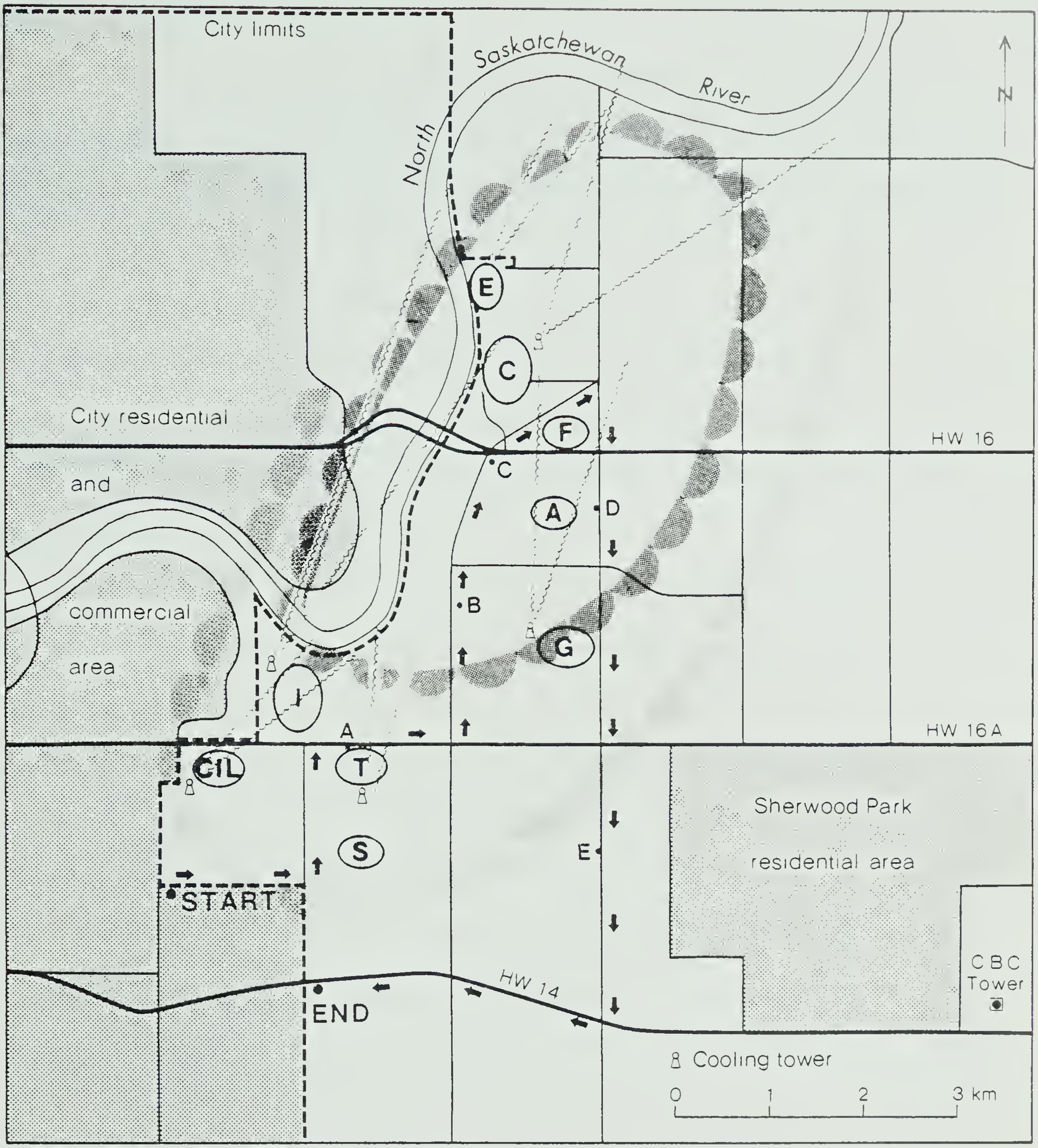
The record cold spell for December lasted from December 4 to 10. Table A-1 of Appendix A indicates that temperatures remained near the overnight minima of $-36.4^{\circ}C$ in the city (YXD), $-39.2^{\circ}C$ north of the city (YED), and $-41.7^{\circ}C$ south of the city (YEG) throughout the day. The radiosonde ascent indicated temperatures were

Table 4.1 Five case studies.

Case #	Date	Temp.	100 m wind	Remarks
1	Dec. 9/77	$-40^{\circ}C$	S light	Record cold spell
2	Jan. 31/78	$-28^{\circ}C$	NW light	Good precipitation samples
3	Mar. 1/78	$-24^{\circ}C$	calm	Heavy precipitation
4	Feb. 1/78	$-32^{\circ}C$	W strong	Bitter cold with wind
5	Jan. 9/80	$-34^{\circ}C$	SW light	Cold with light wind

$-29^{\circ}C$, 800 meters above ground level; a very cold temperature aloft if one considers that true ice fog is observed to form at temperatures lower than $-27^{\circ}C$. CBC tower winds at 91 m (Table A-2) were generally southerly at less than 5 m/s, while surface winds were calm or southerly at about 2 m/s. The radiosonde (Table A-3) indicated that the country air was supersaturated with respect to ice if such data can be considered reliable. Appendix A-1 indicates that ice fog prevailed in the city and rural communities and that the sky was clear or had only a few cirrus clouds.

Figure 4.1 indicates where field observations were made along the route which is identified by arrows. Upon arrival at the industrial area it was obvious that the region of dense fog was caused by low and middle level industrial emissions. Typical visibilities were less than 500 m at points such as A and D in Figure 4.1, but visibilities as low as 50 m prevailed near the



Cooling tower plumes (stack plumes for Edmonton Power)

Approximate fog area Denser

EP Edmonton Power C Celanese F Fiberglas A Alcan G Gulf
I Imperial T Texaco S Stelco CIL C.I.L.

Figure 4.1 Field map for December 9, 1977. T = -40°C (0830 LST), wind light.

Celanese plant.

Plate 4.1 is a panorama taken from point D of Figure 4.1. It indicates that visibilities were low looking westward into the industrial area compared to looking northward or southward along the eastern edge of the industries.

Plate 4.2 was taken from a high point to the southeast of the industries (Point E on Figure 4.1). It indicates that visibilities were good to the south of the industries. Using this plate, the cooling tower plumes from Texaco and Gulf were determined to rise to 130 and 250 m, respectively.

Plate 4.3 is a time exposure taken at night from the thirty-third floor of the AGT building located downtown about 6 km west of Imperial. It shows that by evening (1720 LST) the ice fog was clearing out of the city in the southeast but that the plume from Imperial was clearly visible and persistent as seen just to the north of east. Actually, the plumes illuminated by the city were far more visible to the eye than is indicated in the time exposures and, based on such observations, they were calculated to extend at least 10 km north of their source.

During the morning, precipitation particles were observed at points B, C, and D of Figure 4.1. The fog particles appeared to be typical of ice fog, but with some large frozen particles. That is, they were mostly frozen cloud droplets which in ice fog terminology are called droxtals. Although no Formvar replicas were made, the falling particles were seen to range up to a few hundred micrometers and they were unrimed. Extensive studies of ice fog by

S W N

Plate 4.1 December 9, 1977. Industrial area in a dense ice fog.
Location, D in Figure 4.1
Time, 0920 LST
Temperature, -40°C
Visibilities to W (fog core area) are much lower than to S and N.

NW N

Plate 4.2 December 9, 1977. Plumes ascending through ice fog.
Location, E in Figure 4.1
Time, 0925 LST
Temperature, -40°C
Cooling tower plumes from Texaco (left) and Gulf (right).

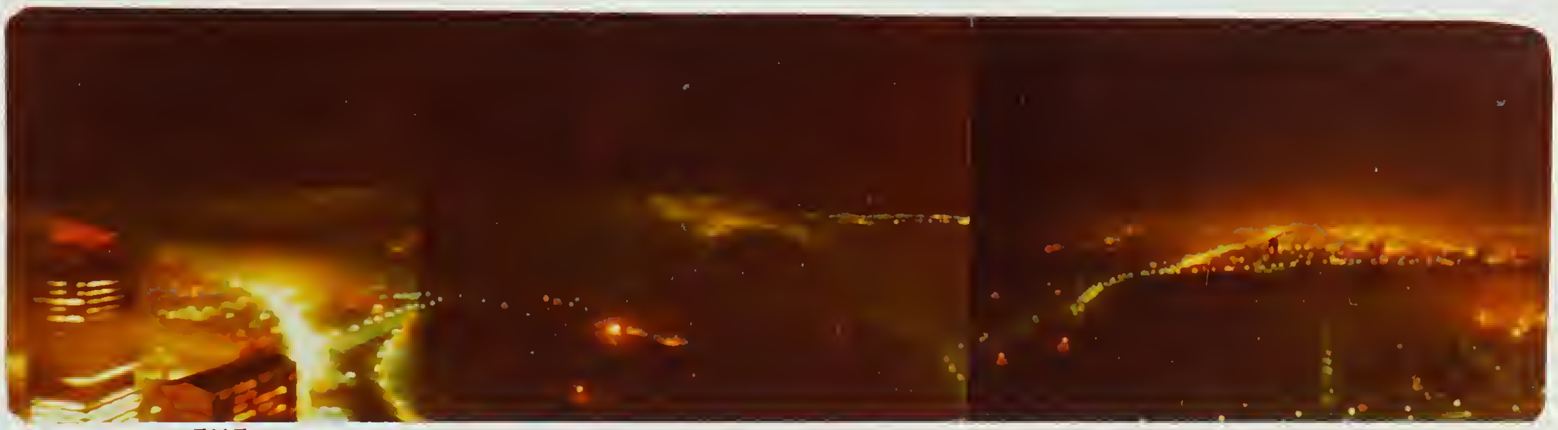


Plate 4.3 December 9, 1977. Industrial plumes at night.
Location, 33rd floor of AGT Building
Time, 1720 LST
Temperature, $-37^{\circ}C$
Cooling tower plume from Imperial is seen on horizon from ENE to E. CIL and Texaco plumes are to ESE. Ice fog to SE was patchy before sunset.

Ohtake (1970) found no such large particles in Fairbanks, only particles smaller than ten micrometers. It is believed that the large particles were coming from cooling tower water which is sprayed downward, but in spite of drift eliminators, some particles escape in the updraft. The lack of riming observed on these frozen drift particles is indicative that cloud size droplets were unable to supercool to the prevailing plume temperatures and subsequently rime onto the more easily frozen drift droplets.

In summary, December 9, 1977 was a very cold day when the industrial area formed deep and locally dense ice fog which drifted several kilometers downwind. Unfortunately, the observations were not designed to clearly determine the ability of the industrial heat plumes to ventilate the industrial area or to find the true end of the industrial plume. Nevertheless, an area of at least fifteen square kilometers was covered by relatively dense ice fog.

4.2 Case 2 - January 31, 1978

During this cold and clear day the temperatures rose from about $-29^{o}C$ to $-24^{o}C$ while the winds at plume level fell off and backed from northerlies through to westerlies.

The meteorological data in Tables B-1 to B-4 of Appendix B include three minisonde soundings (Table B-4) to supplement the radiosonde data (Table B-3) and tower data (Table B-2). All of these soundings show a 100 m deep ground-based inversion in the morning giving way to a nearly isothermal layer 1000 m deep by noon. By mid-afternoon lapse conditions indicated good surface mixing to

about 100 m capped by the stable isothermal layer.

Frequent reports of ice crystals and ice fog at the airports (Table B-1) and sightings of sundogs in the industrial area suggest that the air was saturated with respect to ice. Surface winds were high enough to keep visibilities high at the airports except at 1100 LST when visibility fell to 2.4 km at the Municipal Airport under calm conditions.

The industrial area was studied from 0900 to 1500 LST. The field trip map (Figure 4.2) indicates a large area of light fog with denser fog near the river valley. Several photographs serve to illustrate the persistence of the plumes which were frequently producing precipitation. The points marked by a P in Figure 4.2 indicate where trays were set out to obtain snow samples.

Plate 4.4 shows the CIL and Imperial cooling tower plumes drifting in different directions as viewed from point A. The CIL plume rose to 120 m while that of Imperial rose to 250 m. The Texaco plumes are seen to be nearly obscured by fog coming from the vicinity of Imperial and the combined low and mid-level emissions appear to cause a denser fog in the area of Stelco.

Plate 4.5 is a cyclorama taken near Celanese (point C of Figure 4.2). It shows fog in the valley to the NW and generally good visibilities under the plumes of Edmonton Power (NNW), Celanese (NE), Fiberglas (E), and Gulf (SE). Low and middle level plumes were dissipating quickly at these points despite the fact that sundogs sighted to the east and southeast were indicating ice saturation. Only ice crystals fell in this vicinity of the industrial area.

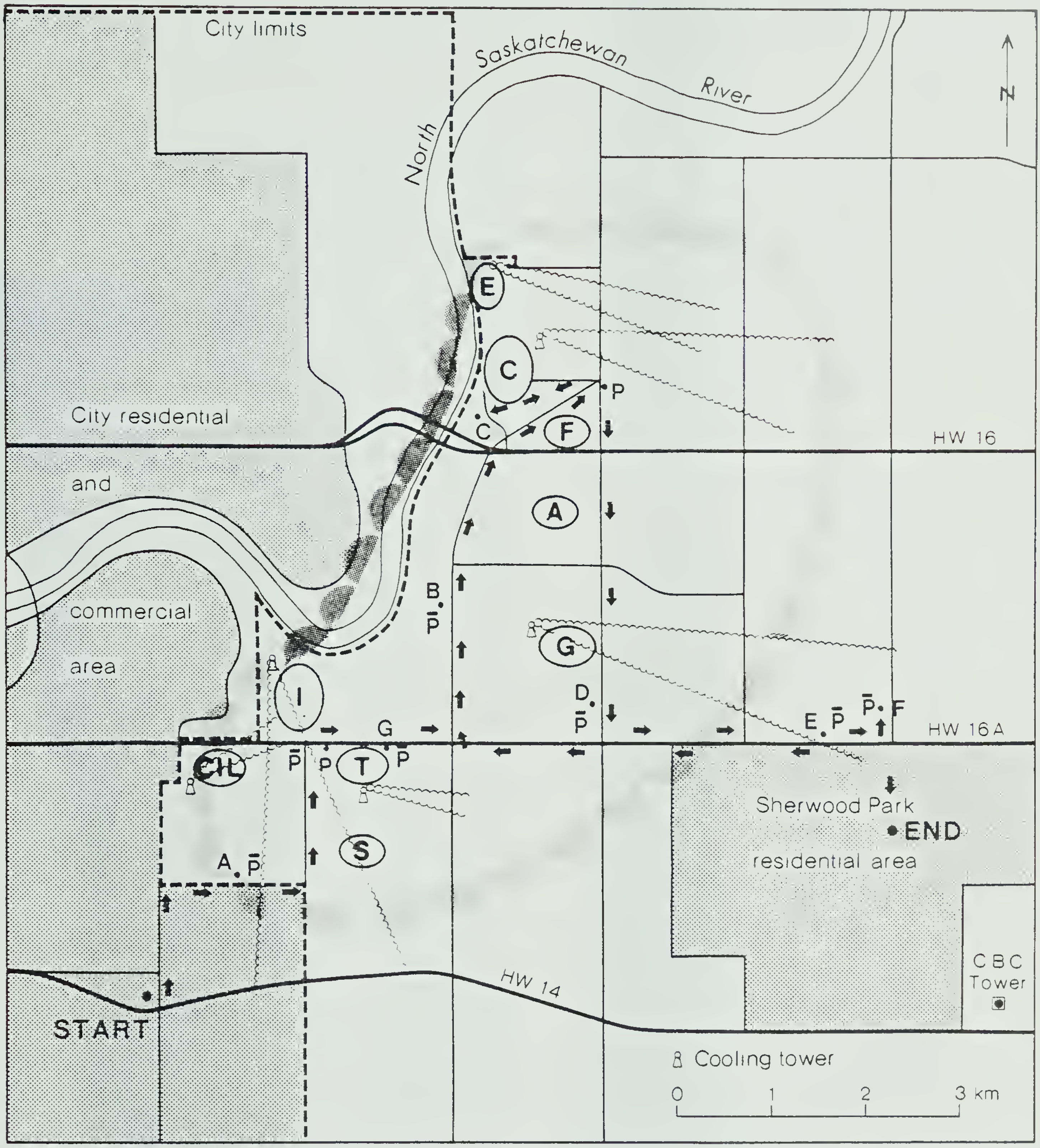


Figure 4.2 Field map for January 31, 1978. T = -28°C (0930 LST), wind light.

Plate 4.4 January 31, 1978. CIL and Imperial cooling tower plumes and ice fog.
Location, A in Figure 4.2
Time, 0940 LST
Temperature, $-29^{\circ}C$
CIL plume is to N and Imperial rises to NNE. Texaco is in fog to NE.

Plate 4.5 January 31, 1978. Cyclorama of Celanese area.
Location, C in Figure 4.2
Time, 1020 LST
Temperature, $-28^{\circ}C$
Valley fog is to NW. Edmonton power plume is to N. Celanese cooling tower rises behind stack plumes to NE.

Plate 4.6 was taken from point F near Sherwood Park (Figure 4.2). The Gulf (WNW) and Celanese (NW) plumes are spreading out and moving toward the camera but they are barely discernible from the general low-level fog which is drifting at least to a point directly north of this location. A snow sampling tray, seen in the foreground, was put out because the plumes seemed to be very persistent in spite of the rather large distance (5 km) to the nearest cooling tower.

Plate 4.7 was taken from point E of Figure 4.2. The Imperial plume in the center and Gulf plume in the upper right illustrate the persistence of the plumes on this date. Precipitation trays were laid out near this point.

Plate 4.8 was taken from point E about three hours after the Plate 4.7 was taken. It shows that the Imperial, Gulf and Celanese plumes had become very persistent as the winds fell off. There is also the strong possibility that the humidity had increased due to a flow of low level air over the city center towards Imperial and Gulf.

Ten precipitation samples were attempted at locations marked $\bar{P}$ on Figure 4.2. Sampling times ranged from 0.2 to 3.2 hours. Seven measurable samples were collected. When each tray was laid out, snow was seen to fall at least sporadically. Table 4.2 gives complete information on the precipitation samples and their probable sources.

Precipitation rates in the order of 0.01 mm/h of water equivalent over a two-hour sampling period are certainly not large but they are sufficient to whiten roadways and make them slippery.

Plate 4.6 January 31, 1978. The industrial area in a general fog.
Location, F in Figure 4.2
Time, 1102 LST
Temperature, -27°C
Gulf plume is to WNW as is precipitation tray. Celanese is seen to NW.

W

Plate 4.7 January 31, 1978. Imperial and Gulf plumes at 1045 LST.
Location, E in Figure 4.2
Time, 1045 LST
Temperature, -28°C
Imperial plume is to W and Gulf plume at upper right.

SW WSW W WNW NW NNW

Plate 4.8 January 31, 1978. Imperial, Gulf, and Celanese plumes at 1345 LST.
Location, E in Figure 4.2
Time, 1345 LST
Temperature, -24°C
Imperial to W, Gulf WNW, and Celanese to NNW.

Table 4.2. January 31, 1978. Precipitation measurements.

Sampling time LST (h)	Mass (g)	Precip rate (water equiv) 10^{-3} mm/h	Location on map	Probable source & distance from location (km)	Plume dimensions height m (length km)
0943-1140 (2)	2.5	1.9	A	Imp (2)	260 (2.5)
1002-1215 (2.2)	0.06	0.04	G	Imp (1.4)	280 (2.5)
1010-1240 (2.5)	16	9.9	B	Imp (2)	280 (2.5)
1038-1323 (2.9)	44.7	24.0	D	Imp (3.5)	300 (2.5)
1045-1358 (3.2)	9.3	4.4	E	Gulf (3.4)	230 (2.5)
1102-1410 (3.1)	16.1	8.0	F	Gulf (4)	260 (2.5)
1410-1420 (0.2)	11.9	110	F	Gulf (4)	260 (4)

Table 4.2 includes the result of a 0.2 h sample taken during a heavy snow shower at point F where visibilities were reduced to less than 1 km looking towards the industries and snowfall rates reached 0.1 mm/h of water equivalent. Such a snowfall rate resulted in a quick whitening of the tray which subsequently disappeared as the fluffy snow was "balled" by very light breezes. "Balling", illustrated in Plates 4.9 and 4.10, became a familiar phenomenon as it appears to be characteristic of the fluffy 1 to 2 mm snowflakes which fall from cooling tower plumes.

Identification of the snowfall sources given in Table 4.2 was made by eye and verified, to some degree, by the minisonde data given in Table B-4. The estimated plume heights and lengths were made visually and by calculations based on photographs, some of which are not included here. No significant snowfalls were seen to come from the smaller cooling towers of CIL or Texaco. That the wind direction at plume level was quite variable is illustrated by the identification in Table 4.2 of the snow sample collected at point B as having come from Imperial during a brief flow from the WSW. This wind direction variability is verified by the tower winds tabulated in Table B-2. They show that at 1200 LST during the sampling period the 91 m winds were indeed from the WSW.

In summary, temperatures at plume height of between -22°C and -25°C were not low enough to glaciate the plumes in the manner of December 9, 1977 and therefore small snow flakes were able to develop on January 31.

Plate 4.9 January 31, 1978. Snow in tray from Imperial, 2.5 h sample.
Location, B in Figure 4.2
Time, 1240 LST
Temperature, $-26^{\circ}C$
Snow balls are caused by breezes in tray.

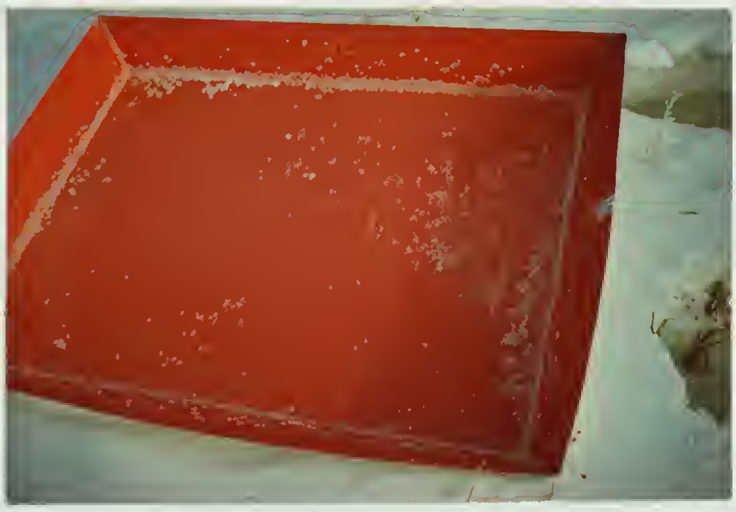


Plate 4.10 January 31, 1978. Snow in tray from Gulf, 0.2 h sample.
Location, F in Figure 4.2
Time, 1420 LST
Temperature, $-24^{\circ}C$
Snow balls are caused by breezes in tray.

4.3 Case 3 - March 1, 1978

During this date's morning field studies the temperatures rose from about -25 to -16°C under conditions of nearly calm winds (Appendix C, Table C-1). Temperatures at 91 m averaged about -17°C (Appendix C, Table C-2) and humidities measured by the Stony Plain radiosonde were around 60% relative to ice saturation (Appendix C, Table C-3) at ground and plume level. The field map (Figure 4.3) indicates a light southwesterly flow at plume height but generally the flow was very light and the plumes frequently spread out in a mushroom shape. The nearly calm winds are the main factor for the heavy snowfall and extensive clouds witnessed on this date.

The field trip map (Figure 4.3) shows three areas of light fog. Visibilities on this date were generally around 8 km in the industrial area with only local areas in the lee of the plantsites having less than 1 km visibilities.

Of greater interest than fog on this date, are the heavy snowfalls such as those shown in Plate 4.11 (point F) and the large quantities of snow collected, as shown in Plates 4.12 and 4.13. Plate 4.14, a panorama taken from point I (Figure 4.3) near Sherwood Park, shows the industrial plumes rising and leaning on the light winds just after sunrise.

Within two hours the winds at plume height were nearly calm (1.3 m/s at the tower, Table C-2) from the southwest and the industrial plumes combined to create the nearly overcast conditions seen in the cyclorama of Plate 4.15 near Celanese (point E). The plates discussed above and other photographs were used to determine

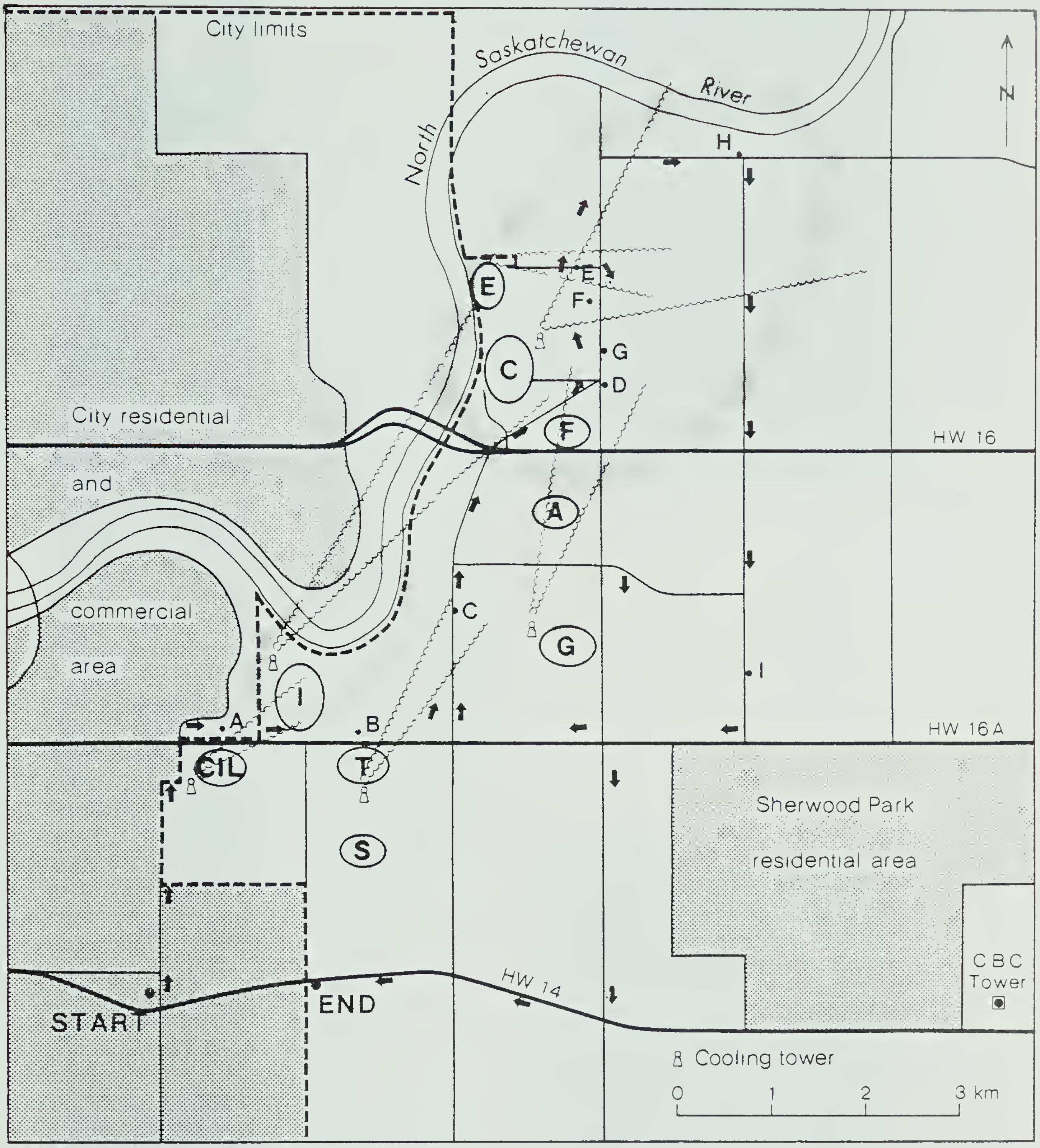


Figure 4.3. Field map for March 1, 1978. T = -24°C (0830 LST), wind nearly calm.

Plate 4.11 March 1, 1978. Snowfalls near Celanese
Location, F in Figure 4.3
Time, 0815 LST
Temperature, $-24^{\circ}C$
Very low visibility to N was caused by a heavy snow shower.

Plate 4.12 March 1, 1978. Snow in tray from heavy snowfall.
Location E in Figure 4.3.
See Table 4.3.

Plate 4.13 March 1, 1978. Snow in tray pushed into a pile.
Location F in Figure 4.3.
See Table 4.3.

WNW NW NNW N NNE NE

Plate 4.14 March 1, 1978. Panorama of industrial area covered by plume clouds.
Location, I in Figure 4.3
Time, 0835 LST
Temperature, $-23^{o}C$
Winds at this time were becoming calm. Gulf plume is to NW and Celanese is between NNW and N rising through haze layer.

Plate 4.15 March 1, 1978. Cyclorama of industrial area nearly overcast in plumes.
Location, E in Figure 4.3
Time, 1020 LST
Temperature, -20°C.

that the plume clouds persisted for more than five kilometers from their sources as they levelled out at the following approximate altitudes: Texaco 70 m, Gulf 170 m, Imperial 240 m, and Celanese 240 m.

Precipitation was sampled at points B, C, D, E, F, and G on the field map (Figure 4.3) and the results are summarized in Table 4.3. Sampling times of from 1.4 to 2.4 h resulted in low precipitation rates in all but two cases. The exceptions were the surprisingly heavy snowfalls from the Celanese plume which was encountered at points E and F where 2.4 and 1.7 h precipitation rates of 0.067 and 0.129 mm/h of water equivalent occurred. The roadways near these two points were well covered by the fresh snow for several hundreds of meters. The collected snow is shown in Plates 4.12 and 4.13 discussed above. This snow shower can be seen in the background of Plate 4.11, but a close-up of the area where visibilities dropped to 100 m in snow was not obtained nor was a short period snow sample such as was obtained on January 31, 1978 (Table 4.2). It is sufficient to state that the precipitation rates encountered during the calm winds of March 1 were much greater than those encountered at lower temperatures but greater wind speeds on January 31.

Replicas of the falling snow were made at the time when the precipitation trays were set out and taken in. The results of studying these replicas under a microscope are given in Chapter V. It is sufficient to state here that the snow particles at all sampling sites were typically less than 1000 μm whether or not their structure

Table 4.3. March 1, 1978. Precipitation measurements.

Sampling time LST (h)	Mass (g)	Precip rate (water equiv) 10^{-3} mm/h	Location on map	Probable source & distance from location (km)	Plume dimensions height (m) length (km)
0716-0908 (1.9)	1.3	1.1	B	Texaco (0.5)	70 (2.5)
0725-0917 (1.9)	7.1	5.8	C	Texaco (2.5)	70 (3)
0745-0930 (1.8)	12.7	10.9	D	Gulf (3.5)	170 (≈4)
0800-1025 (2.4)	104.1	66.7	E	Celanese (1)	240 (≈6?)
0813-0946 (1.6)	130.7	129	F	Celanese (0.8)	240 (≈6?)
0817-0939 (1.4)	3.2	3.6	G	Celanese (0.8)	240 (≈6?)

was primarily crystaline or primarily that of a frozen droplet.

4.4 Case 4 - February 1, 1978

This date was chosen because it combined brisk winds with low temperatures. Appendix D contains the hourly, industrial, tower, radiosonde and minisonde data from which one concludes that winds at plume height (200 m) were westerly at 10 m/s on this clear morning, falling off to 7 m/s by early afternoon. Morning surface temperatures of $-32^{\circ}C$ gave way to $-23^{\circ}C$ in the afternoon as the ground-based inversion dissipated.

The observations for this date are to be compared to previous cases and those of January 9, 1980 (Case 5) which had similar temperatures but light southwesterly winds.

The hourly airport observations (Table D-1) indicate that only the Municipal Airport experienced ice fog and then only during the morning rush hour (0700 to 1000) when visibilities dropped to 1.6 km. The brisk winds caused the rural airports to have high visibilities throughout the morning in spite of -28 to $-35^{\circ}C$ temperatures.

The field trip map (Figure 4.4) indicates three areas of light fog seen just after sunrise when temperatures were around $-32^{\circ}C$. Lowest visibilities of 1.5 to 2 km were in the fog area near Imperial and Texaco. Plate 4.16, taken from point A (Figure 4.4), shows this fog area, and Plate 4.17 was taken from the same point in the early afternoon after the fog had blown away when the inversion dissipated.

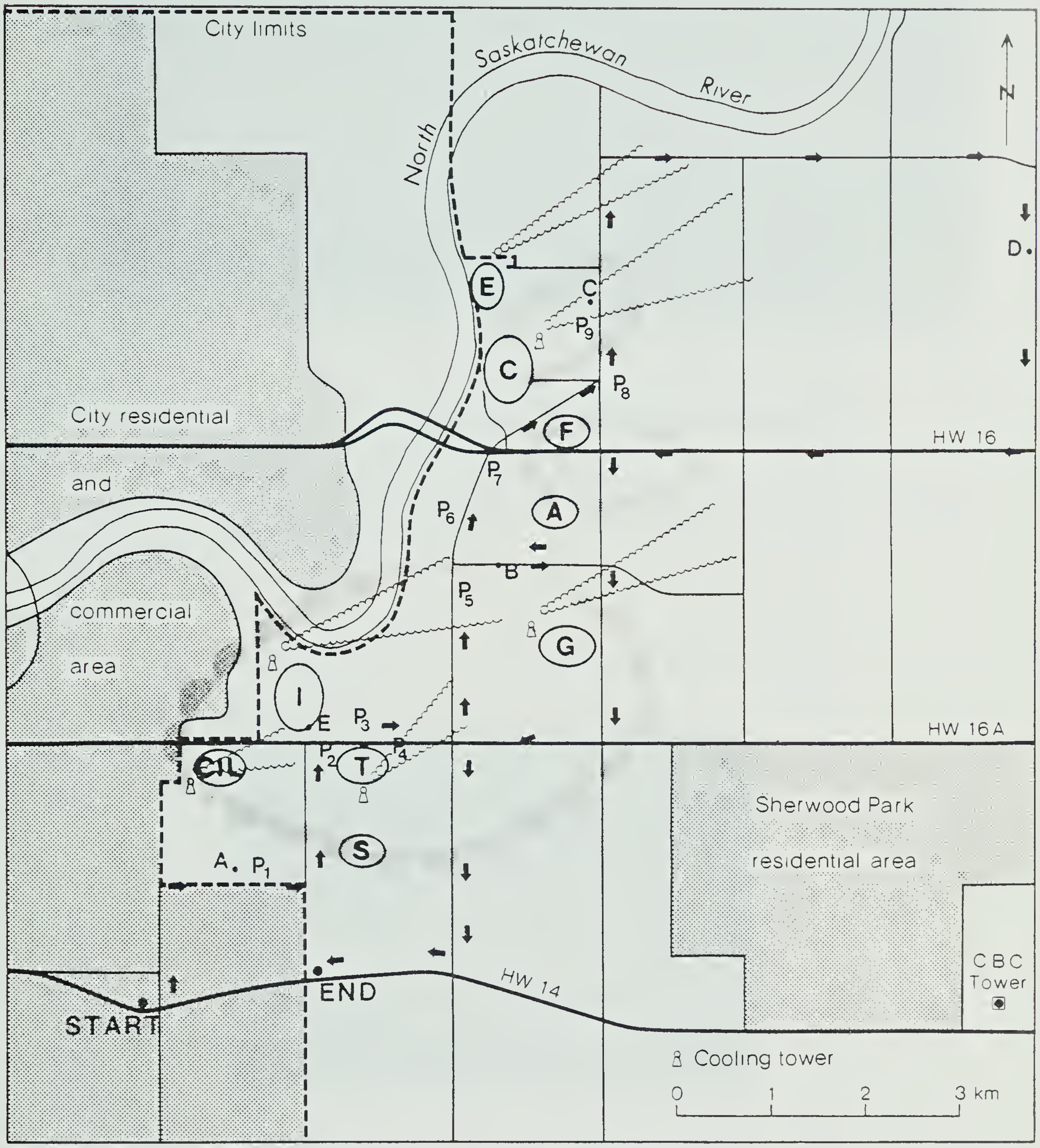


Figure 4.4. Field map for February 1, 1978. T = -32°C (0900 LST), wind strong.

N NE

Plate 4.16 February 1, 1978. Fog near Imperial in early morning on windy day.
Location, A in Figure 4.4
Time, 0840 LST
Temperature, -32°C.

N

Plate 4.17 February 1, 1978. Afternoon view showing industries free from fog observed in Plate 4.16.
Location, A in Figure 4.4. Same as Plate 4.16.
Time, 1345 LST
Temperature, -24°C.

Plate 4.18 (point C) shows the plumes of Celanese and Edmonton Power in the mid-afternoon. Strong winds restricted plume rise from large cooling towers to between 80 and 170 m until late in the afternoon. The field map indicates plume lengths of between 2 and 3 km and Plate 4.18 shows the fanning nature of the plumes. Plate 4.19 shows the Gulf plume and a steam vent from Alcan taken an hour after Plate 4.18 when winds at plume height were finally falling off (5 m/s). Careful inspection of Gulf's cooling tower in Plate 4.19 shows some ground level cloud apparently caused by reversed flow in some cooling tower cells to remove excess icing. On less windy days these flow reversals can contribute to fog formation.

In summary, the brisk winds reduced the rise of the cooling tower plumes but their lengths were typical of the prevailing temperatures. Industrial fog formed only in the early morning when temperatures were near -32°C and the influence of the city was not apparent in the industrial area despite the air's track from city to industry.

Nine precipitation trays were set out (points P in Figure 4.4) but on returning, six were found to be flipped over and blown about by the wind. The remaining trays showed a few frozen drift particles with diameters of a few hundred micrometers and some fluffy balled snowflakes. Apparently the cloud parcels in the plumes on this windy day did not exist long enough for the development of significant snowfalls. This is strikingly different from the snowfalls observed in Case 2 when light winds prevailed at lower temperatures and Case 3 when calm winds prevailed at higher temperatures.

Plate 4.18 February 1, 1978. Plumes from Celanese (SW-W) and Edmonton Power (WNW-NNW).
Location, C in Figure 4.4 Time, 1443 LST Temperature, -22°C

Plate 4.19 February 1, 1978. Plumes from Gulf (WSW) and a steam vent from Alcan (WNW).
Location, B in Figure 4.4 Time, 1550 LST Temperature, -22°C

The snowfalls in all cases covered to this point differ from the one reported by Kramer et al. (1976) where giant cooling towers, much larger than those studied here, triggered the development of seemingly natural convective clouds which subsequently drifted and developed snowfall 13 to 43 km downwind.

4.5 Case 5 - January 9, 1980

On this clear and cold day temperatures rose from about -34°C in the morning to about -31°C in the mid-afternoon (Appendix E, Table E-1), while winds at plume height were mainly light southwesterlies, falling off during the afternoon from about 4 m/s to 2 m/s (Tables E-3 and E-4). The tower data (Table E-2) indicate that a strong surface-based inversion gave way to nearly neutral stability during the afternoon. Four minisonde soundings (Table E-4) indicate that plume temperatures ranged between -24 and -27°C.

Ice fog prevailed at the city airport (Table E-1) throughout most of the day, giving 1 km visibilities in the morning and slightly better visibilities with occasional periods of good visibility during the afternoon. The rural airports reported ice crystals or ice fogs throughout the day with visibilities of 5 km or more except at Namao Airport where visibilities fell to 1.6 km on two morning hourlies.

The field trip map (Figure 4.5) shows the large area (20 km^2) of dense ice fog which persisted during the morning. This is in sharp contrast to conditions on February 1, 1978 (Figure 4.4) when temperatures were slightly higher and winds were brisk.

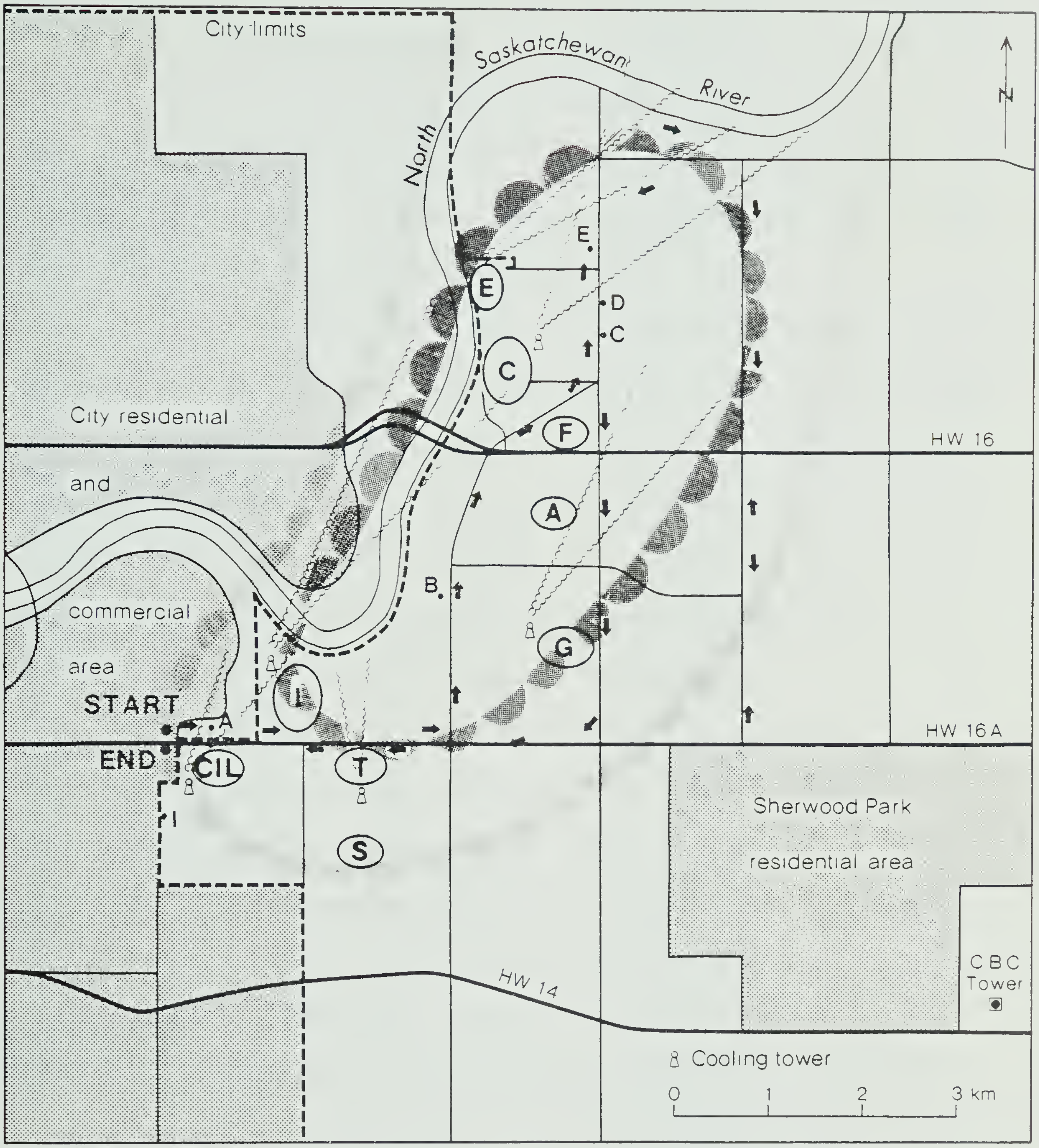


Figure 4.5. Field map for January 9, 1980. T = -34°C (0930 LST), wind light.

During the morning of January 9, 1980 it was difficult to photograph the major plumes because of intervening fog (visibilities of 100 m to a few hundred meters) but they were seen to rise to 250 to 300 m, nearly twice as high as on February 1, 1978 during brisk winds. The depth of the industrial fog was in many cases as deep as these major plumes. Fine snow fell continuously from the cooling tower plumes and a few ice crystals fell from the fog.

During the afternoon trip to the industrial area visibilities had risen to 1 to 3 km with local 500 m visibilities. Snow continued to fall from the plumes of the major cooling towers. Plate 4.20 shows this improved visibility as seen from the southwest corner of the industrial area (point I, Figure 4.5). Plate 4.21, taken just before sunset, shows the persistent snowing plumes seen from the center of the industrial area (point B, Figure 4.5).

Five precipitation sampling trays were set out (points P, Figure 4.5) during the morning field trip and gathered about six hours later during the afternoon trip. Table 4.4 summarizes these samples and gives the most probable sources of the precipitation along with estimates of the contributing plume's rise and length. Only two trays had substantial precipitation rates (points B and E, Figure 4.5). Precipitation rates measured near Celanese (points C, D, and E, Figure 4.5) are probably from multiple plumes since the plumes from the plants to the southwest were drifting towards Celanese. Table 4.4 indicates that precipitation rates are highest downwind of the largest sources if one takes into account the occasional wind direction changes during a six hour period. Neverthe-

Plate 4.20 January 9, 1980. Plumes from several plants seen after dense fog dissipated.
Location, I in Figure 4.5
Time, 1520 LST
Temperature, $-29^{\circ}C$
The plumes near NNE are: CIL barely visible, Imperial two large, and Texaco three smaller.

Plate 4.21 January 9, 1980. Cyclorama of persistent snowing plumes seen from the center of the industrial area.
Location, B in Figure 4.5
Time, 1555 LST
Temperature, $-28^{\circ}C$
Low and moderately low visibilities had persisted throughout the day.

Table 4.4. January 9, 1980. Precipitation measurements.

Sampling time LST (h)	Mass (g)	Precip rate (water equiv) 10^{-3} mm/h	Location on map	Probable source & distance from location (km)	Plume dimensions height (m) length (km)
0935-1535 (6)	4.5	1.2	A	CIL (0.5)	100 (1.6)
0947-1555 (6.1)	74.5	18.7	B	Imperial (1.9)	250 (≃6)
1010-1620 (6.2)	116.5	29.0	E	Celanese (1.3)	230 (≃6)
1014-1640 (6.4)	13.5	3.2	D	Celanese (0.8)	230 (≃6)
1014-1640 (6.4)	16.5	3.9	C	Celanese (0.8)	230 (≃6)

less, on this date even small plumes such as CIL were producing snowfall (point A in Figure 4.5 and Table 4.4).

In summary, the high humidities indicated by ice crystal phenomena at rural locations and the relatively low temperatures at plume level (-24 to -27°C) produced an industrial fog and plume regime which was comparable to that of the coldest observation date, December 9, 1977 (-40°C), despite the fact that the ice fog (droxtal) phenomenon was not prevalent on January 9, 1977. It was also observed that precipitation fell more readily on January 9, 1977 than on the coldest day and that the precipitation was more crystalline than that of warmer days such as March 1, 1978 when the precipitation primarily consisted of rimed frozen drift droplets.

4.6 Weather summary in 5°C intervals

Table 4.5 gives a summary of the industrial weather observations taken on 36 cold days, most of which were made in the morning under clear sky conditions. The following is a discussion of the data entered under the five main columns of Table 4.5. Each column's data is broken down according to five degree intervals of surface temperature. Basic data for each day is given in Appendix F.

Column 1 gives the five degree interval and, in brackets, the number of dates of field observations which are best represented by that temperature range. Each day was put into a temperature range after it had been concluded that the industrial area's temperatures are more characteristic of rural areas than urban areas. For instance, the lowest temperatures for the three winters measured

Table 4.5. Weather summary in $5^{o}C$ intervals.

#1	#2			#3	#4		#5
Category	Low Temperature Fog			91 m Wind	Plume Data		Snowfall
Temp. °C (# days)	% days with IC (with IF)	visibility mean km (minimum)	fog extent	mean m/s snow days (all days)		height range (length range)	median 10^{-3} mm/h maximum 10^{-3} mm/h # samples/# days % precip. days
-15 to -20	20	10.6	local	3	A	60 - 130 m (0.7 - 2.5 km)	5 129
(10)	(0)	(<0.2 in snow)		(7)	B	150 - 300 m (1.2 - 5 km)	11/3 30
-20 to -25	43	9.3	local	3	A	70 - 140 m (0.7 - 2.5 km)	13 38
(7)	(14)	(<0.3 in snow)		(6)	B	170 - 310 m (1.6 - 4.5 km)	9/3 29
-25 to -30	75	5.4	general	3	A	70 - 140 m (0.8 - 2.5 km)	11 110
(12)	(75)	(<0.1 in fog and snow)		(5)	B	180 - 310 m (1.6 - 5 km)	18/6 67
-30 to -35	83	3.5	general	3	A	70 - 140 m (1 - 2.5 km)	4 29
(6)	(100)	(<<0.1 in fog and snow)		(4)	B	250 - 310 m (1.6 - 6 km)	5/1 83
-35 to -40	100	1.5	general	4	A	90 - 130 m (≃2 - 3 km)	NA NA
(1)	(100)	(<<0.1 in fog)		(4)	B	250 - 300 m (8-10 or longer km)	NA 100

In column 4 - A: for small towers including CIL and Texaco cooling towers
B: for large towers including Imperial, Gulf, and Celanese cooling towers

at the downtown airport were -36.4, -32.4, and -33.6°C; those of the rural international airport were -44.6, -40.1, and -36.8°C; while those taken at Celanese were -40, -40, and -36°C. These Celanese temperatures were recorded on December 9, 1977, February 15, 1979, and January 9, 1980, the first and last of which have been treated as case studies in this thesis.

Column 2 gives the percent of days with ice crystals (IC) and ice fog (IF), mean and minimum visibilities and general fog characteristics, all by 5°C intervals. This column indicates that industrial ice fog and ice crystal phenomena become much more frequent at temperatures lower than -25°C, and they are nearly assured at temperatures below -30°C. As stated earlier, ice crystals are indicative of the ambient air being saturated with respect to ice and are identified by their scintillation in sunshine. Column 2 also indicates that the lowest local visibilities at temperatures above -25°C are caused by industrial snowfall rather than fog. Based on thirty-six days of observation, it appears that brisk winds and low upwind humidity are factors which impede cloud and fog formation, but due to the lack of a large number of observation dates it is impossible to realistically calculate statistics based on these factors at 5°C intervals. Another field observation about fog is that when ice fog forms it is generally only a few tens of meters deep and covers twenty to fifty square kilometers. With the correct combination of light wind and high humidity it can extend to plume heights of 300 m and cover a much larger area downwind of the industries. It was also observed that the dense fog which forms over the river does not normally drift out of the river valley.

Column 3 of Table 4.5 gives mean 91 m wind speeds from the CBC tower for the observation dates. The upper figure is for days when cooling tower snowfall was observed and the lower figure is the average for all dates in the particular temperature interval. Light winds are more typical of colder days and days when snow forms. Nevertheless, this column also indicates that light winds are a major factor in development of cooling tower snowfalls on relatively mild days.

Column 4 of Table 4.5 gives the range of plume rises and visible lengths for small (A) and large (B) cooling towers for the temperature intervals. Plume rise is more variable at the higher temperatures because there is a greater likelihood of stronger winds. Visible plume lengths can vary greatly at a given surface temperature, apparently because of wind speed, humidity and vertical stability factors. However, the truly persistent plumes, having lengths of 5 km or more, were generally associated with temperatures colder than $-25^{\circ}C$ at plume height.

Column 5 of Table 4.5 gives four factors associated with snowfall sampling. The first number in each temperature category gives the median snowfall rate for non-zero samples, while the second number gives the maximum rate regardless of exposure time. These data indicate no strong dependence of snowfall maximum or median rates upon temperature. The third entry in this column gives the total number of industrial snowfall samples obtained and the number of days when a non-zero sample was obtained. The largest number of days of snowfall sampling (6) falls in the -25 to $-30^{\circ}C$ range just as the largest number of field trips (12, see column 1)

were executed in that range. This reflects the author's enthusiasm for performing field trips at temperatures lower than -25°C and the scarcity of days colder than -30°C. The bottom entry in each temperature category gives the percent of field trips during which industrial precipitation was observed but not necessarily collected. This entry is therefore not proportional to the 'number of days' entry under column 5 divided by the 'number of days' entry under column 1. It gives a rather accurate indication of how the probability of industrial precipitation rises from about 30% on days between -15 and -25°C to about 100% on -35 to -40°C days.

In summary, Table 4.5 gives an overall picture of the industrial area during cold weather. The observations made on all thirty-six field trips were of similar detail to that shown in the five case studies. Nevertheless, it was felt that complete discussion and data tabulation for all dates was beyond the scope of this report and, therefore, the limited data given in Appendix F will suffice.

CHAPTER V

MICROPHYSICS OF INDUSTRIAL SNOW

The techniques used to make Formvar slide replicas of industrial snow particles have been described in Section 4 of Chapter III. The first section of this chapter describes laboratory techniques used to analyze the replicas and the second section gives the results of analyzing 1413 snow particles replicated on the slides. These microphysical studies included comparison of the snow particles to natural snow crystals and an assessment of the contribution of cooling tower drift particles to the industrial snowfall.

5.1 Analysis techniques

The first two columns of Table 5.1 indicate that 66 replica slides were made at 32 locations on ten days. Analysis of the slides was not strictly random since those with few particles were scrutinized closely until particles were found, while those with many particles were only analyzed for a fraction of their particles. Slides exposed at the same location at approximately the same time

Table 5.1. Snow particles by date and drift origin.

Date	replica #	All snow particles #	from drift #	from drift %	> 500 μm particles #	from drift #	from drift %	> 500 μm crystals #	from drift #	from drift %
1978										
Feb 15	1	27	11	41	2	2	100	0	0	-
	2	11	8	73	6	6	100	0	0	-
Feb 16	1	2	0	0	1	0	0	1	0	0
Feb 28	1&2	15	11	73	5	3	60	0	0	-
	3&4	37	22	59	21	13	62	2	0	0
	5&6	17	10	59	11	9	82	2	1	50
Mar 1	1&2	15	12	80	6	5	83	2	1	50
	3	16	7	44	5	3	60	2	1	50
	4	48	23	48	22	9	41	11	4	36
	5	35	12	34	16	7	44	3	0	0
	6&7	21	17	81	11	9	82	2	1	50
	8	15	7	47	1	0	0	0	0	-
	9	38	4	11	24	2	8	20	2	10
	10	106	31	29	35	4	11	32	4	13
Dec 28	1-3	173	61	32	7	2	29	3	1	33
	4&5	82	21	26	7	7	100	1	1	100
	6&7	21	11	52	10	7	70	1	0	0
Dec 29	1-3	4	2	50	0	0	-	0	0	-
	4-6	25	12	48	1	0	0	0	0	-
	7-9	22	10	45	4	2	50	1	0	0
1979										
Jan 2	1-3	33	8	24	4	4	100	1	0	0
	4-6	41	15	37	10	4	40	3	1	33
	7-9	15	2	13	10	5	50	3	1	33
Jan 13	1-3	33	11	33	12	7	58	1	0	0
Jan 14	1&2	22	5	23	12	4	33	7	3	43
	3-5	20	6	30	11	6	55	4	1	25
Feb 17	1-3	52	20	38	26	12	46	16	6	38
	4&5	88	41	47	30	13	43	11	3	27
	6&7	92	26	28	28	15	54	16	6	38
	8-9	78	30	38	30	10	33	5	1	20
	10&11	101	31	31	31	9	29	10	3	30
	12-14	108	28	26	21	14	67	1	0	0
Grand Totals		1413	515	36%	420	193	46%	161	41	25%

of day were treated as the same. Most analyses were conducted visually through the microscope. These analyses were further documented in nearly two hundred photographs of snow particles which were printed at up to X70 magnification. Twenty of these photographs are included here as plates 5.1 through 5.20. In all, 1413 snow particles were analyzed according to type, extent of cloud droplet riming, overall particle composition and extent of drift drops which were taken to be any drop larger than 50 μm in size.

Particle typing was done according to the World Meteorological Organization scheme, as described by Mason (1971) with some modifications based on the more detailed classification of Magono and Lee (1966). The Field Guide to Snow Crystals by E.R. La Chapelle (1969) was also useful in crystal identification. Particle types which grow by vapor deposition are either hexagonal plates, stellar crystals (including feathery six-sided dendrites), columns, needles, spatial dendrites (not planar) or irregular crystals. Aggregates of several crystals are called flakes. Snow particles that grow by the riming of supercooled droplets are called snow pellets (also graupel). Frozen drizzle or frozen cooling tower drift drops are classified as ice pellets. Particles smaller than 250 μm are, by convention, classified as germ particles. They are abundant at very low temperatures but are generally found to contribute little to the total mass of precipitation. Size ranges used in the classification are shown in Table 5.2. Frozen ice spheres of more than 50 μm diameter are classified as drift droplets in this study since simple calculations show that such particles are very unlikely to

Table 5.2. Number of crystals: size vs. habit: 1977-78 and 1978-79.

		Size range µm						
		0 to 125	125 to 250	250 to 500	500 to 1000	1000 to 2000	2000 to ∞	Totals
NEEDLE	total	10	8	9	8	0	1	36
	rimed	8	4	5	4	0	1	22
	drift	0	0	2	2	0	0	4
PLATE	total	61	86	70	28	1	0	246
	rimed	41	65	42	21	1	0	170
	drift	1	12	26	8	0	0	47
COLUMN	total	61	73	34	12	0	0	180
	rimed	39	36	22	6	0	0	103
	drift	0	2	2	2	0	0	6
IRREGU-LAR	total	9	21	37	35	4	2	108
	rimed	7	13	30	22	2	2	76
	drift	3	6	4	14	1	1	29
ICE PELLET	total	36	90	95	68	9	1	299
	rimed	21	86	80	63	9	1	260
	drift	20	84	87	64	7	1	263
SNOW PELLET	total	23	37	42	40	0	0	142
	rimed	23	36	42	40	0	0	141
	drift	6	12	20	25	0	0	63
STELLAR	total	4	21	27	37	4	1	94
	rimed	3	14	23	31	4	1	76
	drift	1	3	10	11	2	0	27
SPATIAL DENRITE	total	3	25	21	26	6	2	83
	rimed	1	20	21	21	6	2	71
	drift	1	4	14	8	3	1	31
FLAKE	total	3	31	56	71	57	7	225
	rimed	2	23	50	58	46	7	186
	drift	1	13	35	33	19	3	104
TOTALS	total	210	392	391	325	81	14	1413
	rimed	145	297	315	266	68	14	1105
	drift	33	136	200	167	32	6	574

form by the coalescence of the abundant 10 μm cloud droplets in an industrial plume (Mason, 1971 or Pruppacher and Klett, 1978).

The degree to which each particle had grown by riming was compared to its crystalline growth by vapor deposition. Very generally, the conditions favoring growth of a snow pellet by riming are either a large cloud water content or a drift drop embryo because it can collect cloud droplets efficiently. If ice crystals predominate they have a tendency to aggregate into snow flakes which are also efficient rimers.

Although cloud droplets are readily cooled to -30°C before they freeze, drops larger than 100 μm have a rapidly increasing probability of freezing as their temperature falls from -20 to -25°C (Mason, 1971 or Leighton, 1977). Therefore, the snow replica interpretation proceeded on the assumption that drift size droplets would have frozen quickly after leaving the cooling tower.

Figure 5.1 illustrates some of the growth possibilities of a precipitation particle on a cooling tower plume. It shows how the embryo is a frozen drift drop which becomes the center of a competition between its riming to a snow pellet and its growth to a six-sided crystal. In the figure, crystalline growth by vapor deposition appears to have prevailed. As growth of the six-sided plate begins, the particle's fallspeed would be reduced as would its ability to collect rime. Riming of plates is summarized by Pruppacher and Klett (1978) where they show that when the plate has grown to a few hundred micrometers, the particle would regain its ability to rime along its edges and particularly at the corners as illustrated

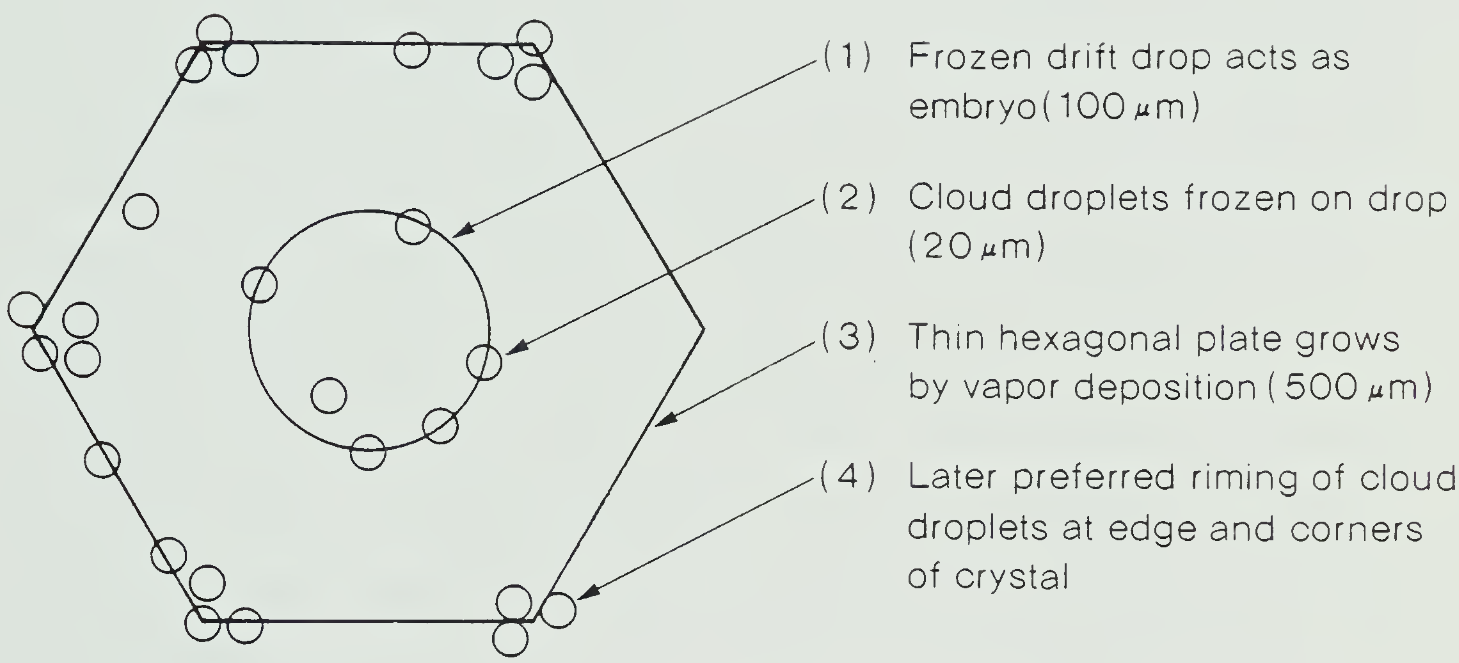


Figure 5.1 Typical growth modes of a precipitation particle in a cooling tower plume at -25°C.

in Figure 5.1. If the cloud water content of the plume is high enough, heavy riming can lead to formation of a large snow pellet which would completely hide the central crystal.

The laboratory techniques and cloud physics information given above lead to the results of the crystal replica analysis which follows.

5.2 Results of the snow particle analysis

Table 5.1 shows the distribution of snow particles according to date and drift origin. Drift origin in this table means that the snow particle was clearly seen to have grown around a frozen droplet of size greater than 50 μm, a situation which existed for 36% of all particles. The columns which refer to all particles greater than 500 μm show that 46% of these large particles originated as drift drops. Of those particles which were predominantly crystalline and larger than 500 μm, only 25% could be identified as having originated as drift.

The data in Table 5.1 suggests that there are large variations in abundance of large particles relative to small ones and that the abundance of drift droplet embryos is also variable. Attempts to understand these variations by considering sampling location, plume source and meteorological parameters were generally unfruitful. Nevertheless, analysis according to temperature revealed that planar crystals tended to develop at temperatures above -25°C and prism-shaped crystals dominated at lower temperatures. This situation is expected for natural snow particles, but in the case of

cooling tower snow, there were occasions when both plates and prisms seemed to co-exist. The analysis also revealed a tendency for smaller crystals at lower temperatures as would be expected in natural snowfalls.

For comparative purposes, several Formvar replicas of natural snow particles were made on cold days. None of the natural snow particles on the slides contained drift-sized drops at their center or rimed on their edges. In summary, Table 5.1 indicates that drift droplets play a major but variable role in the formation of industrial snow particles and comparison to natural snow reveals that natural snow does not depend on large drops for its development.

Table 5.2 summarizes the industrial snow crystals by size range and particle type. It reveals that all of the basic types of natural snow were present in the industrial snowfall but, unlike natural snowfalls at low temperatures, industrial snow particles are generally less than 1000 μm in size and they are frequently identified as ice pellets. Experience, rather than experiment, suggests that the frequency of rimed particles (1105 out of 1413) is much higher in industrial plumes than in natural snowfall at these temperatures. The identification of drift size droplets in Table 5.2 is somewhat different than in Table 5.1 since Table 5.2 counts the presence of all drift size drops rather than just those which appeared to act as a central embryo for the snow particle, i.e., 515 were clearly of drift origin, while 574 contained drift drops.

Table 5.3 compares the size distributions of snow particles and drift particles in percentage terms. The snow distribution is

Table 5.3. Size distributions of snow particles and drift particles.

	%	
Category	Snow Distribution	Drift Distribution
0 - 125 µm	15	27
125 - 250 µm	28	54
250 - 500 µm	28	14
500 - 1000 µm	23	5
1 - 2 mm	6	0.3
2 - 4 mm	1	0.1
4 - 8 mm	0.3	0.0
Total %	100	100
Investigated	1413	1342

based on data in Table 5.2. The drift distribution is based on counts of all drift size droplets encountered. Notice that 1342 drift droplets were counted on the 574 particles reported in the previous paragraph to contain at least one drift drop. The table indicates that snow particles are mainly in the three ranges between 125 and 1000 μm while drift droplets heavily favour the 125 to 250 μm size range. The drift distribution compares well with size distributions reported by Martin and Barber (1974) except that they found fewer drops in the larger categories. Future measurements of drift size distributions at the outlets of the cooling towers in the Strathcona industrial area could be compared to the distribution in Table 5.3.

Plates 5.1 through 5.20 show a selection of the snow particles encountered. Their captions include information about the collection data, probable industrial source, distance from source and temperature on that date. The snow particles illustrated in these plates are prejudiced towards larger frozen droplets. Nevertheless, they reveal typical particles and the importance of cooling tower drift drops in the formation of industrial snow. Since each plate is accompanied by a brief description, they need not be discussed here.

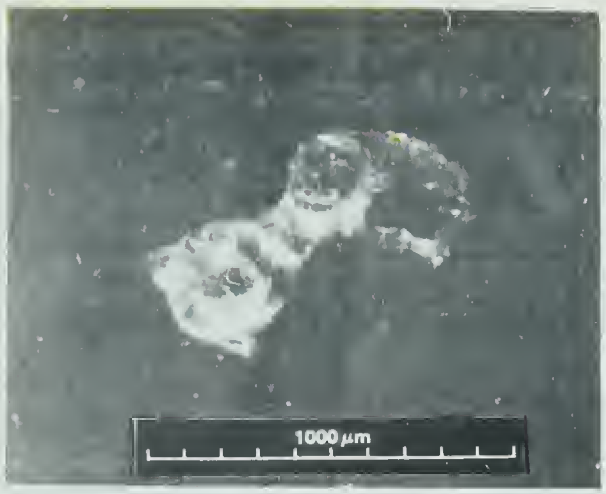


Plate 5.1 Clumped frozen drift particles.
0850 LST, Jan. 13, 1979
1 km from Imperial
T = -30°C

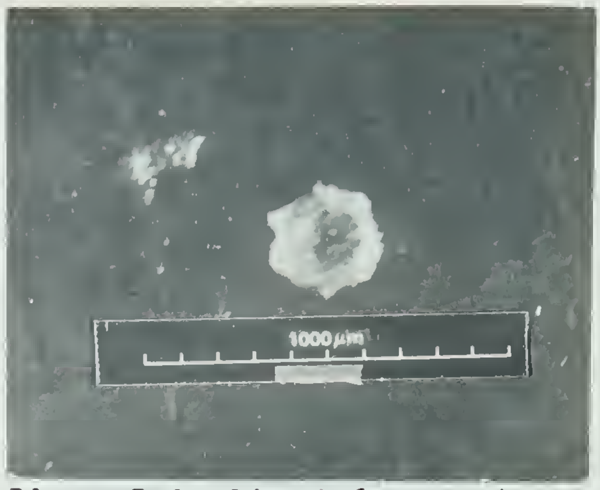


Plate 5.2 Rimed frozen droplets.
1100 LST, Jan. 14, 1979
1 km from Gulf
T = -26°C

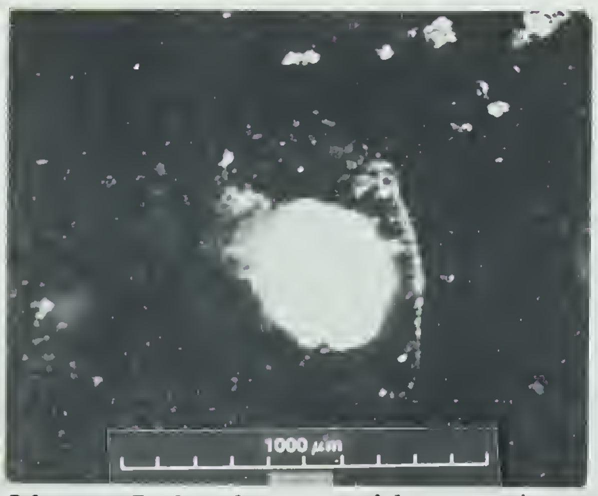


Plate 5.3 Snow pellet and smaller particles.
1310 LST, Feb. 17, 1979
1.2 km from Imperial
T = -24°C

Plate 5.4 Two heavily rimed drift particles.
1030 LST, Jan. 2, 1979
0.9 km from Gulf
T = -25°C

Plate 5.5 Rimed drift with spikes?
1100 LST, Dec. 28, 1978
0.9 km from Celanese
T = -25°C

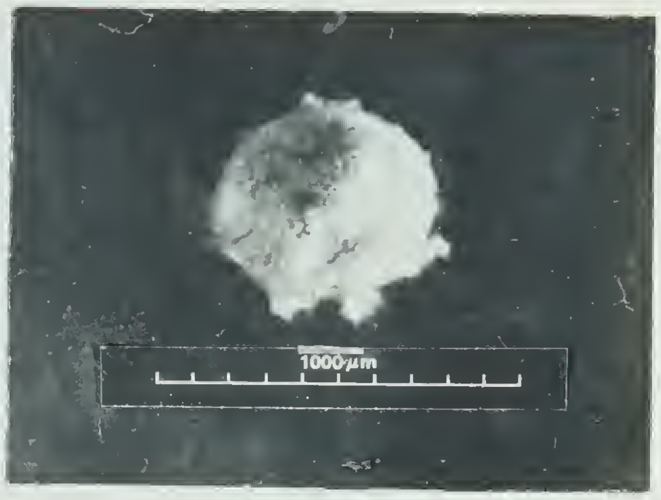


Plate 5.6 Rimed drift with spikes?
0940 LST, Feb. 17, 1979
1.3 km from Celanese
T = -30°C

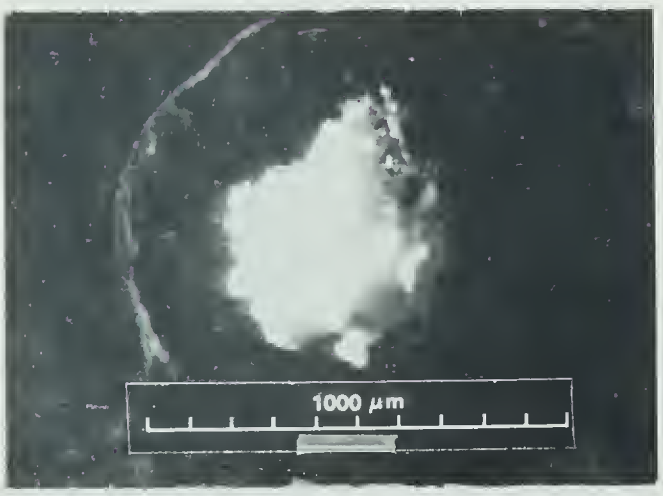


Plate 5.7 Heavily rimed snow pellet.
1310 LST, Feb. 17, 1979
1.2 km from Imperial
T = -24°C

Plate 5.8 Small rimed hexagonal plates.
1130 LST, Dec. 29, 1978
3.3 km from Gulf
T = -26°C

Plate 5.9 Heavily rimed drift and three smaller. (Ignore scratches.)
0840 LST, Jan. 2, 1979
0.9 km from Gulf
T = -25°C

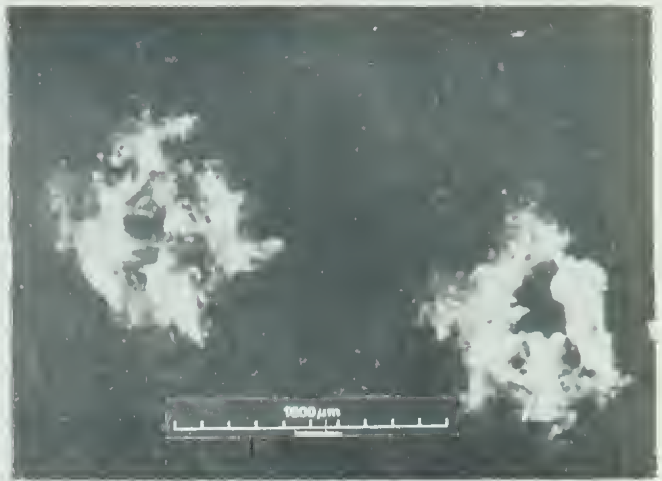


Plate 5.10 Two rimed snowflakes (from frozen drift?).
0815 LST, Mar. 1, 1978
0.8 km from Celanese
T = -23°C

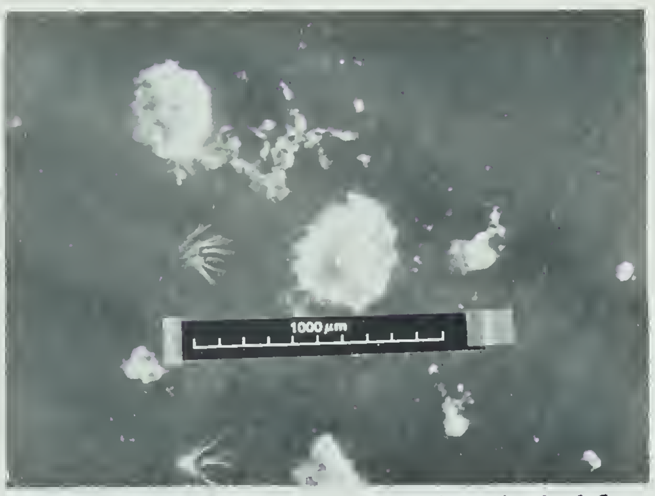


Plate 5.11 Densely rimed drift particles.
0930 LST, Feb. 17, 1979
1.3 km from Celanese
T = -28°C

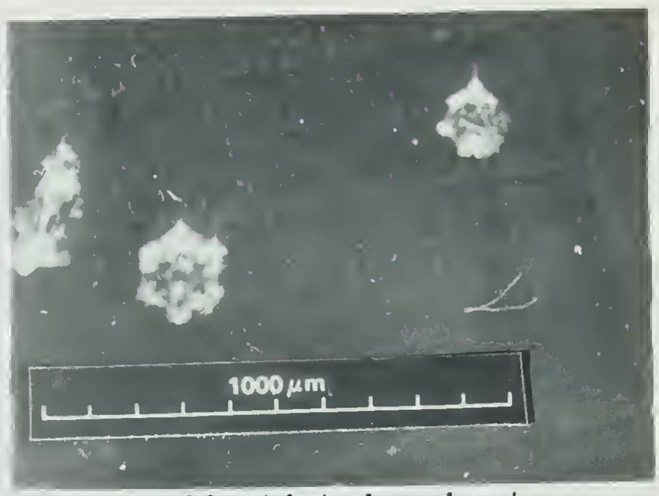


Plate 5.12 Lightly rimed hexagonal plates.
1115, Jan. 2, 1979
0.9 km from Gulf
T = -22°C

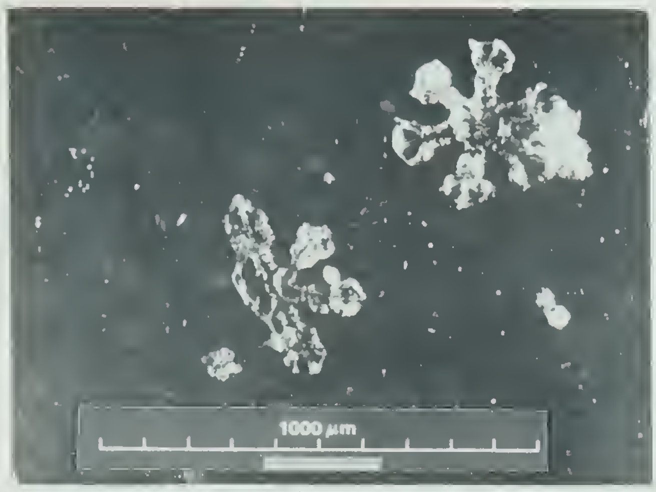


Plate 5.13 Lightly rimed stellar crystals. (Spherical drift centers?)
0815 LST, Mar. 1, 1978
0.8 km from Celanese
T = -23°C

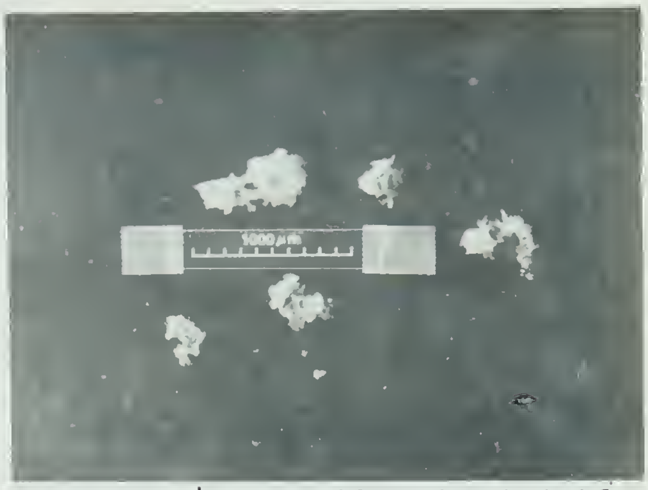


Plate 5.14 Heavily rimed drift with clumping (above scale).
0936 LST, Jan. 2, 1979
2.2 km from Celanese
T = -24°C

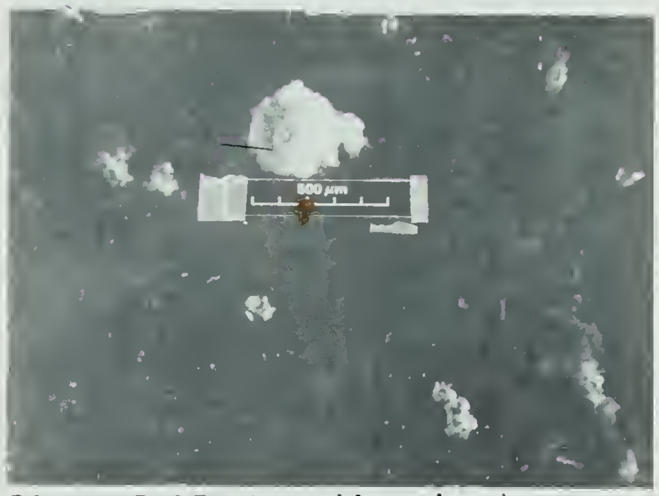


Plate 5.15 Heavily rimed drift particles.
1210 LST, Feb. 17, 1979
0.5 km from CIL
T = -22°C

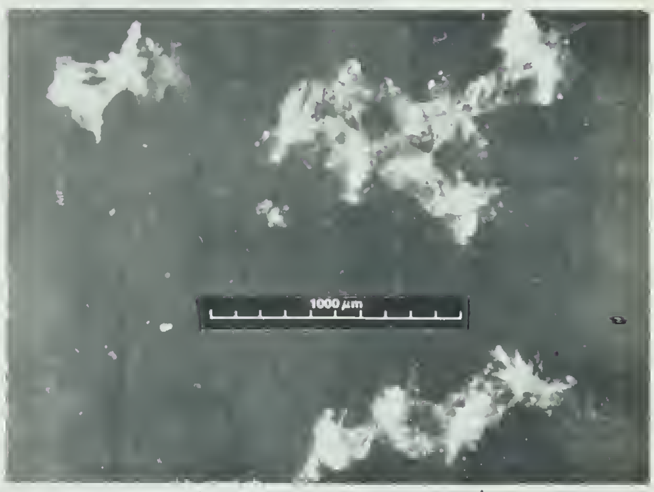


Plate 5.16 Snowflakes (from drift?).
1025 LST, Mar. 1, 1978
1.1 km from Celanese
T = -20°C

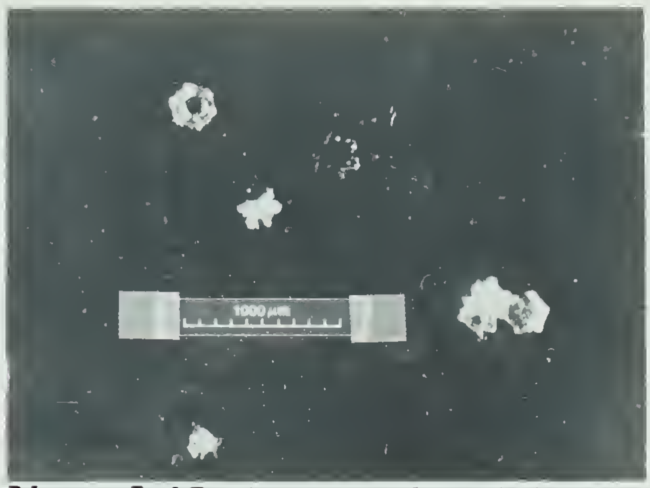


Plate 5.17 Hexagonal and irregular (above scale) crystals.
0845 LST, Feb. 15, 1978
1.2 km from CIL
T = -21°C

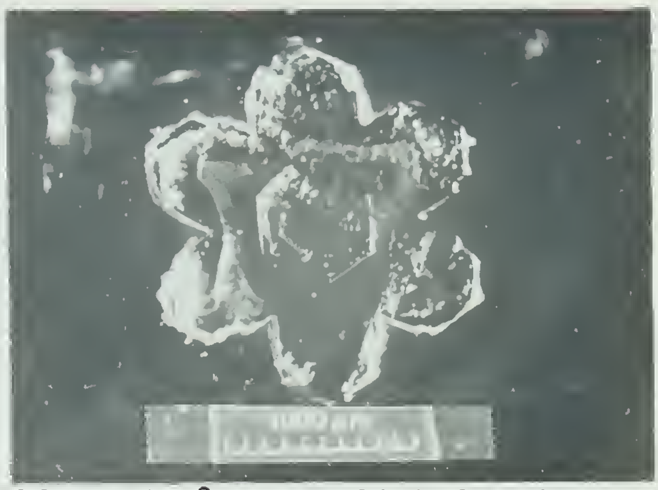


Plate 5.18 Very lightly rimed sector plate.
1025 LST, Mar. 1, 1978
1.1 km from Celanese
T = -20°C

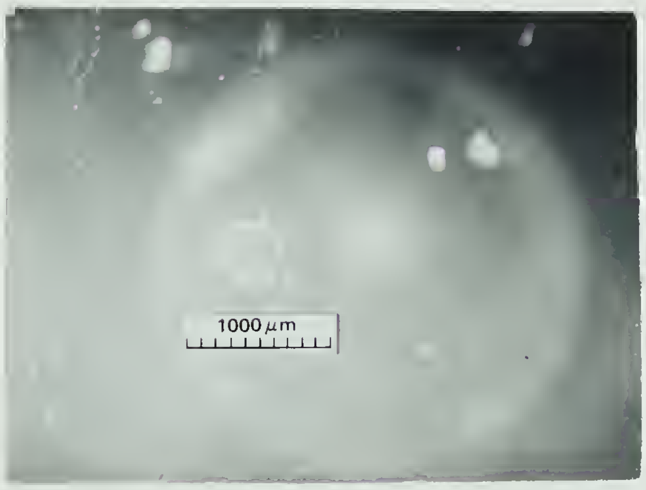


Plate 5.19 Sector plate with rimed edges (above scale).
0850 LST, Feb. 15, 1978
1.2 km from CIL
T = -20°C

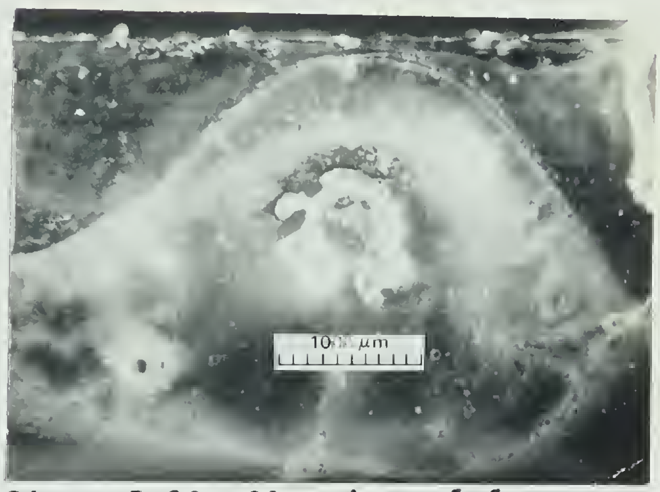


Plate 5.20 Clumping of frozen drift. (Ignore surface irregularity.)
0850 LST, Feb. 15, 1978
1.2 km from CIL
T = -20°C

CHAPTER VI

CONCLUSIONS

The Strathcona industrial area is a suitable place to investigate the potential for the formation of fog, cloud, and snow by industries at more northerly locations. If latent heat is included, the area's total power loss to the atmosphere is more than 3 GW, a figure which is of the order of that of the city of Edmonton and other industrial complexes.

Fog does not usually restrict visibility throughout the Strathcona industrial area at temperatures above -25°C. Below that temperature, clear morning visibilities are restricted throughout the area on most days with visibilities reduced locally to a few hundred meters. Observations indicate that the thermal breezes caused by the larger plants prevent thick fog throughout the area until temperatures of -35°C are reached, whereupon deep ice fog sets in with visibilities dropping locally to 50 m.

Cooling tower plumes are usually about 2 km long at temperatures above -35°C but at lower temperatures the plumes become very persistent as an ice fog phenomenon sets in. On days with nearly calm winds and moderately low temperatures the plumes can become wide-spread to the extent where, from certain vantage points, the sky appears to

be overcast.

Precipitation rates from the large plumes are typically 10^{-2} mm/h of water equivalent which is barely enough to cover roadways. However, snowfalls of more than 0.1 mm/h were encountered and they did whiten roadways and make driving hazardous when the visibility fell below 100 m. The heaviest snowfalls occurred within 1 km of the source on a day with nearly calm wind conditions and temperatures of $-19^{\circ}C$. Surprisingly, heavy snowfalls were also encountered at a distance of nearly 4 km on mornings with average winds and $-27^{\circ}C$ temperatures.

Formvar plastic replicas were found to be a convenient way to document the microphysics of the snow particles. They reveal the size distributions of the snow particles and the drift drops as well as the shape and degree of riming of the particles. The replicas indicate that snowfall from cooling towers is highly influenced by drift droplets at the temperatures under study.

Future studies could include an air column trajectory model to predict the formation of fog and a plume dispersal model to give cloud water distributions for use in a snow particle growth model.

Future field work should include portable temperature, humidity, and precipitation moisture measurements. They are expected to reveal rather sharp variations in space and time.

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APPENDIX A

WEATHER DATA

December 9, 1977

Table A-1. December 9, 1977. Hourly observations.
a - YED, b - YXD, c - YEG

Time (LST)		T (°C)	T_d (°C)	R.H. (ice) (%)	Wind (km/h)	Weather & Vis. (km)	Cloud amt, 1/10s (base, km)	Pcpn
0600	a)	-37.8	-42.5	61(91)	Calm	IFIC 0.8	F 10	
	b)	-36.1	-42.2	50(78)	Calm	IFIC 0.4	F 10	
	c)	-41.7	M	M	Calm	IFIC 0.4	F 1	
0700	a)	-38.6	-43.7	59(88)	Calm	IFIC 0.4	F 10	
	b)	-34.9	-41.7	50(71)	Calm	IFIC 0.4	F 10	
	c)	-41.6	M	M	Calm	IFIC 0.6	F 2	
0800	a)	-37.2	-42.6	57(84)	Calm	IFIC 1.2	Ci 1 (7.5)	
	b)	-34.4	-41.1	51(72)	Calm	IFIC 0.2	F 9	
	c)	-40.5	M	M	Calm	IFIC 0.6	Ci 2 (6.6)	
0900	a)	-36.6	-41.1	59(86)	Calm	IF 0.8	Ci 1 (7.5)	
	b)	-34.8	-41.2	52(75)	SSW 6	IFIC 0.2	F 10	
	c)	-39.5	-43.6	65(96)	SSE 7	IF 0.4	Ci 3 (6.6)	
1000	a)	-36.8	-41.3	63(92)	Calm	IFIC 0.8	Ci 3 (7.5)	
	b)	-34.6	-40.2	57(81)	SSW 7	IFIC 0	F 10	
	c)	-38.9	-42.0	68(100)	SE 4	IF 0.8	Ci 3 (6.6)	
1100	a)	-36.9	-41.3	64(93)	Calm	IFIC 0.4	Ci 4 (7.5)	Tr
	b)	-34.2	-39.7	57(81)	SW 7	IFIC 0.2	Ci 1 (7.5)	Tr
	c)	-37.2	-42.0	63(93)	SE 7	-- 13	Ci 7 (6.6)	Tr
1200	a)	-37.3	-41.6	64(94)	Calm	IF 0.8	Ci 3 (6.6	
	b)	-32.2	-38.4	57(78)	Calm	IFIC 0.4	F 10	
	c)	-35.7	-40.0	65(93)	Calm	IF 3.2	Ci 6 (6.3)	
1300	a)	-36.1	-40.7	64(92)	Calm	IF 0.8	Ci 5 (6.6)	
	b)	-31.8	-37.7	56(77)	ESE 7	IFIC 0.6	F 10	
	c)	-34.6	-38.9	65(92)	SE 4	IF 2.3	Ci 8 (6)	
1400	a)	-36.1	-40.7	62(90)	Calm	IF 0.8	Cs 6 (6.6)	
	b)	-31.6	-37.2	58(79)	SSE 7	IFIC 1.2	F 9	
	c)	-34.4	-38.8	64(91)	SE 11	IF 9.6	Ci 7 (6)	

continued ...

Table A-1, continued:

1500	a) -35.9	-40.2	65(93)	Calm		IF	1.6	Cs 2 (6.6)	
	b) -31.5	-37.3	57(77)	ESE	11	IFIC	6.4	Ci 2 (6.6)	
	c) -33.7	-38.3	63(88)	SE	11	--	24	Ac 1 (4.5)	
1600	a) -35.7	-39.8	66(95)	Calm		IF	1.6	Cs 3 (6.6)	
	b) -32.7	-38.7	55(06)	E	9	IFIC	0.8	Ci 1 (6.6)	
	c) -34.1	-38.8	62(87)	SE	7	--	24	Ac 3 (4.5)	
1700	a) -36.3	-40.9	62(91)	Calm		IC	1.6	Ci 2 (7.5)	Tr
	b) -33.7	-39.6	55(78)	E	7	IFIC	0.8	Ci 1 (6.6)	Tr
	c) -33.7	-38.6	61(86)	ESE	11	--	24	Ac 7 (4.5)	Tr
1800	a) -36.4	-40.9	63(92)	Calm		IF	1.6	Ci 2 (7.5)	
	b) -34.1	-39.1	56(82)	E	6	IFIC	0.8	F 9	
	c) -33.4	-38.1	62(87)	ESE	13	--	24	Ac 5 (4.5)	
1900	a) -36.3	-40.8	63(91)	Calm		IF	3.2	Ci 1 (7.5)	
	b) -32.8	-38.9	54(76)	E	6	IFIC	12	F 9	
	c) -33.6	-38.4	62(87)	ESE	13	--	24	Ac 5 (4.5)	
2000	a) -36.0	-40.5	63(91)	Calm		IF	3.2	CiCi 1 (7.5)	
	b) -33.2	-39.2	55(77)	E	6	IFIC	1.2	F 9	
	c) -33.9	-38.9	61(85)	ESE	11	--	24	Ac 3 (4.5)	

Table A-2. December 9, 1977. Plant site and tower data.

Time (LST)	Celanese T (^oC)	Gulf wind (m/s)	CBC Tower 9 m T (^oC)	91 m T (^oC)	γ (^oC/100 m)	91 m Wind (m/s)
0700		NE 1.3	-37.5	-33.9	-4.40	S 2.9
0800	-40	NE 1.3	-37.5	-33.7	-4.61	S 4.4
0900		S 1.8	-37.5	-35.0	-3.05	S 4.9
1000		SE 1.3	-35.0	-33.6	-1.76	S 5.3
1100		SE 1.3	-33.3	-33.8	0.61	SSE 4.4
1200	-36	SE 1.8	-32.5	-33.7	1.46	S 3.1
1300		NE 1.8	-31.9	-33.1	1.46	SSE 3.6
1400		NE 1.8	-31.9	-32.8	1.10	SSE 2.7
1500		NE 2.2	-31.7	-32.5	1.10	SE 3.1
1600	-37	NE 1.8	-32.2	-32.8	0.68	SSE 4.0
1700		NE 1.8	-32.5	-32.9	0.54	SE 5.3
1800		NE 1.3	-32.5	-23.0	0.61	SSE 6.2
1900		NE 1.8	-33.1	-33.5	0.54	SE 4.9
2000	-37	NE 0.9	-33.6	-34.1	0.54	SE 4.4

Table A-3. December 9, 1977. Radiosonde soundings, Stony Plain.

Pressure (mb)	Height (m)	T (^{o}C)	γ (^{o}C/100 m)	T_d (^{o}C)	Mixing ratio (g/kg)	R.H. (ice) (%)	Moisture deficit (ice) (g/kg)	Wind (m/s)
0500 LST								
1000	349							
942	766	-36.9	-3.04	-40.2	0.123	71 (104)	-0.049(+0.004)	SE 2.0
927	878	-33.5	-0.72	-36.6	0.181	74 (103)	-0.065(+0.006)	
854	1459	-29.3	0.00	-29.3	0.398	100 (135)	-0.00 (+0.103)	
850	1493	-29.3		-29.3	0.400	100 (135)	-0.00 (+0.104)	SSE 7.5
1700 LST								
1000	297							
935	766	-35.9	-1.80	-39.2	0.137	72 (103)	-0.055(+0.004)	ENE 3.0
903	1010	-31.5	0.63	-34.0	0.240	78 (108)	-0.066(+0.018)	
887	1136	-32.3	-0.93	-35.3	0.215	75 (104)	-0.073(+0.008)	
850	1438	-29.5		-31.2	0.334	85 (115)	-0.058(+0.044)	SSE 9.0

APPENDIX B

WEATHER DATA

January 31, 1978

Table B-1. January 31, 1978. Hourly observations.
a - YED, b - YXD, c - YEG

Time (LST)		T (^{o}C)	T_d (^{o}C)	R.H. (ice) (%)	Wind (km/h)		Weather & Vis. (km)		Cloud amt, 1/10s (base, km)	Pcpn
0600	a)	-28.7	-33.4	61(84)	W	11	--	24	CLR	
	b)	-27.6	-31.7	68(88)	WNW	15	--	24	CLR	
	c)	-27.6	-31.8	67(87)	Calm		--	24	CLR	
0700	a)	-29.7	-34.4	64(85)	WNW	11	--	24	CLR	
	b)	-26.7	-30.7	70(90)	W	7	IC	24	CLR	
	c)	-28.9	-38.5	45(65)	Calm		--	24	CLR	
0800	a)	-30.0	-35.0	62(83)	W	11	--	19	Ci 1 (7.5)	
	b)	-27.4	-37.0	73(95)	WNW	4	IC	16	CLR	
	c)	-29.1	-34.9	57(78)	SW	4	IF	10	Sc 1 (0.75)	
0900	a)	-29.4	-34.4	62(83)	W	9	IC	16	Ci 1 (7.5)	
	b)	-26.8	-30.4	71(92)	WSW	6	IFIC	6	Ci 1 (6.6)	
	c)	-31.8	-36.1	66(90)	SW	6	IFIC	10	Ac 1 (4.5)	
1000	a)	-28.0	-32.6	65(84)	W	11	IC	24	Ci 1 (7.5)	
	b)	-25.7	-29.9	68(86)	W	6	IFIC	6	Ci 1 (6.6)	
	c)	-29.7	-33.2	72(95)	SW	4	IFIC	10	Sc 1 (0.6)	
1100	a)	-27.1	-31.6	66(85)	W	9	IC	24	Ci 1 (7.5)	Tr
	b)	-24.9	-28.9	69(85)	Calm		IFIC	2.4	Ci 1 (6.6)	Tr
	c)	-27.8	-30.4	78(100)	Calm		IFIC	10	Ac 1 (4.5)	Tr
1200	a)	-26.0	-30.4	66(85)	WSW	7	IC	24	Ci 1 (7.5)	
	b)	-23.7	-27.1	73(91)	S	6	IFIC	6	Ci 1 (6.6)	
	c)	-26.4	-29.4	76(97)	Calm		IC	16	Ci 1 (7.5)	
1300	a)	-24.8	-29.1	67(85)	Calm		--	24	CLR	
	b)	-22.7	-26.5	71(87)	Calm		IC	13	Ci 1 (6.6)	
	c)	-25.5	-28.4	77(97)	S	2	IC	16	Ci 1 (7.5)	
1400	a)	-24.8	-29.3	66(83)	W	7	--	24	CLR	
	b)	-22.0	-25.6	73(88)	W	4	IC	16	SF 1 (0.2)	
	c)	-24.9	-28.4	77(93)	Calm		IC	16	Ci 1 (7.5)	
1500	a)	-24.8	-29.3	66(83)	WNW	4	--	24	CLR	
	b)	-22.9	-27.1	68(84)	N	4	IFIC	6	F2	
	c)	-24.4	-27.2	78(98)	SW	2	IC	24	K 1	
1600	a)	-23.7	-28.2	67(82)	W	4	--	24	CLR	
	b)	-23.5	-28.7	68(85)	N	4	IC	16	CLR	
	c)	-24.5	-29.6	63(81)	Calm		--	24	Ci 1 (7.5)	

Table B-2. January 31, 1978. Plant site and tower data.

Time (LST)	Celanese T (^{o}C)	Gulf wind (m/s)	CBC Tower 9 m T (^{o}C)	CBC Tower 91 m T (^{o}C)	CBC Tower γ (^{o}C/100 m)	CBC Tower 91 m wind (m/s)
0700		SW 4.0	-28.9	-26.1	-3.39	NNW 5.5
0800	-29	SW 4.0	-28.9	-26.1	-3.39	N 5.3
0900		SW 3.6	-27.5	-25.7	-1.90	N 4.0
1000		SW 2.7	-26.7	-25.1	-1.90	NNW 3.1
1100		SW 3.1	-26.1	-25.2	-1.08	WNW 2.7
1200	-26	SW 3.6	-25.6	-25.4	-0.14	WSW 3.6
1300		S 4.4	-24.4	-25.0	0.68	W 2.7
1400		S 2.2	-23.3	-23.9	0.68	W 2.2
1500		S 3.6	-23.3	-24.1	0.95	WSW 1.3
1600	-24	S 3.6	-24.5	-24.5	0.00	SW 0.9

Table B-3. January 31, 1978. Radiosonde soundings, Stony Plain.

Pressure (mb)	Height (m)	T (^{o}C)	γ (^{o}C/100 m)	T_d (^{o}C)	Mixing ratio (g/kg)	R.H. (ice) (%)	Moisture deficit (ice) (g/kg)	Wind (m/s)
0500 LST								
1000	297							
939	766	-25.3	-1.92	-26.7	0.461	88 (114)	-0.062(+0.050)	W 3.6
923	891	-22.9	0.79	-24.2	0.588	89 (113)	-0.072(+0.068)	
882	1222	-25.5	0.23	-27.1	0.473	86 (112)	-0.074(+0.053)	
850	1480	-26.1		-30.4	0.360	67 (88)	-0.177(-0.050)	NW 7.4
1700 LST								
1000	272							
935	766	-21.1	1.40	-24.8	0.585	77 (96)	-0.178(-0.026)	WNW 1.0
892	1110	-25.9	-0.10	-29.0	0.392	75 (98)	-0.130(-0.007)	
872	1274	-25.3	-2.86	-30.1	0.362	64 (83)	-0.202(-0.072)	
867	1316	-24.1	0.42	-33.1	0.273	43 (55)	-0.359(-0.219)	
850	1460	-24.7		-33.6	0.265	43 (56)	-0.345(-0.207)	NW 5.7

Table B-4. January 31, 1978. Minisonde soundings, Ellerslie.

Time (LST)	0910		1100		1400	
Height (m)	Temp (^{o}C)	Wind (m/s)	Temp (^{o}C)	Wind (m/s)	Temp (^{o}C)	Wind (m/s)
0	-34.2	SW 2.3	-29.0	SW 1.8	-23.5	SSW 1.3
22	-26.2	-	-21.6	WSW M	-	-
108	-22.8	W 2.5	-21.2	W 4.1	-22.8	WSW 0.7
216	-22.2	NNW 4.0	-21.1	W 3.3	-23.1	WNW 1.4
315	-22.3	N 4.3	-21.2	NW 1.3	-23.3	W 1.8
414	-22.2	NW 3.2	-21.4	W 1.7	-23.7	WNW 2.6
513	-22.5	NW 4.5	-21.9	WNW 2.6	-23.6	NNW 0.9
612	-22.6	NW 4.7	-21.9	NNW 2.9	-23.7	NW 1.1
706	-22.7	NW 6.2	-21.5	N 4.6	-23.6	NW 4.7
801	-22.7	NW 7.0	-21.6	NNW 7.5	-23.6	WNW 3.2
895	-23.0	NW 7.1	-21.9	NNW 7.9	-23.7	W 5.3
990	-23.3	NW 6.8	-22.2	NNW 7.7	-23.7	W 7.4
1080	-23.8	NW 5.6	-22.1	NNW 7.3	-23.6	WNW 6.6

APPENDIX C

WEATHER DATA

March 1, 1978

Table C-1. March 1, 1978. Hourly observations.
a - YED, b - YXD, c - YEG

Time (LST)		T (°C)	T_d (°C)	R.H. (ice) (%)	Wind (km/h)	Weather & Vis. (km)	Cloud amt, 1/10s (base, km)	Pcpn
0700	a)	-24.3	-27.9	72(95)	W 4	IF 8	K 1 (0.03)	
	b)	-23.5	-26.7	75(95)	SSW 7	-- 13	CLR	
	c)	-29.1	-34.9	57(77)	SSW 7	-- 16	CLR	
0800	a)	-24.2	-28.4	68(87)	WSW 7	IF 8	Ac 1 (3)	
	b)	-23.5	-26.8	74(94)	SW 6	-- 13	Ci 1 (7.5)	
	c)	-28.1	-33.6	59(79)	SSW 7	-- 16	Ci 1 (6.9)	
0900	a)	-22.2	-26.1	73(91)	SW 4	IF 6.4	Ac 1 (3)	
	b)	-22.2	-25.5	74(93)	S 4	IF 6.4	Ci 1 (7.5)	
	c)	-26.2	-31.9	51(97)	S 4	-- 16	Ci 1 (6.9)	
1000	a)	-21.8	-24.9	76(94)	Calm	IF 6.4	Ac 1 (3)	
	b)	-19.3	-22.1	78(96)	Calm	IF 6.4	Sc 1 (0.9)	
	c)	-23.9	-28.1	68(87)	S 4	-- 16	Ac 1 (3)	
1100	a)	-21.1	-25.2	69(86)	Calm	IF 6	CLR	
	b)	-17.6	-21.3	72(87)	Calm	IF 6	Sc 1 (0.9)	
	c)	-21.4	-25.5	69(87)	Calm	-- 16	Ac 1 (3)	
1200	a)	-18.4	-22.1	73(87)	Calm	IF 8	Ac 1 (2.7)	
	b)	-16.3	-20.1	71(83)	WNW 4	H 8	K 1 (0.03)	
	c)	-19.2	-23.2	71(86)	Calm	-- 24	Ac 1 (3)	
1300	a)	-15.7	-19.7	69(81)	Calm	IF 8	Ac 1 (2.7)	
	b)	-14.4	-18.5	69(80)	Calm	H 10	K 1 (0.03)	
	c)	-17.3	-21.4	70(85)	Calm	-- 24	Ac 1 (2.7)	

Table C-2. March 1, 1978. Plant site and tower data

			CBC Tower			
Time (LST)	Celanese T (^{o}C)	Gulf wind (m/s)	9 m T (^{o}C)	91 m T (^{o}C)	γ (^{o}C/100 m)	91 m wind (m/s)
0700		S 1.8	-23.3	-16.2	-7.44	Calm
0800	-23	S 2.2	-23.3	-17.0	-7.68	SSE 1.3
0900		S 2.2	-21.7	-17.3	-5.37	SE 1.3
1000		S 1.3	-18.3	-17.7	0.81	ESE 1.3
1100		S 0.4	-15.0	-15.8	0.98	NNE 1.3
1200	-15	S 0.9	-14.4	-15.0	0.73	NNE 1.3
1300		S 0.9	-13.3	-14.1	0.98	NNE 1.8

Table C-3. March 1, 1978. Radiosonde soundings, Stony Plain.

Pressure (mb)	Height (m)	T (^{o}C)	γ (^{o}C/100 m)	T_d (^{o}C)	Mixing ratio (g/kg)	R.H. (ice) (%)	Moisture deficit (ice) (g/kg)	Wind (m/s)
0500 LST								
1000	188							
926	766	-21.7		-29.4	0.364	50 (62)	-0.368(-0.219)	NNE 2.1
917	839	-14.7	-9.59	-21.7	0.738	55 (65)	-0.600(-0.404)	
895	1024	-12.5	-1.19	-27.5	0.449	27 (31)	-1.193(-0.983)	
871	1231	-12.7	0.10	-29.7	0.376	23 (26)	-1.284(-1.069)	
850	1417	-14.7	1.08	-26.7	0.509	35 (41)	-0.936(-0.724)	N 2.1
1700 LST								
1000	249							
932	766	-11.7		-23.7	0.609	36 (41)	-1.073(-0.869)	ENE 3.1
921	857	-13.5	1.98	-23.5	0.627	43 (49)	-0.844(-0.643)	
850	1464	-16.5	0.49	-20.7	0.869	70 (83)	-0.375(-0.174)	ENE 8.8

APPENDIX D

WEATHER DATA

February 1, 1978

Table D-1. February 1, 1978. Hourly observations.
a - YED, b - YXD, c - YEG

Time (LST)		T (°C)	T_d (°C)	R.H. (ice) (%)	Wind (km/h)	Weather & Vis. (km)		Cloud amt, 1/10s (base, km)	Pcpn
0600	a)	-31.4	-36.9	58(79)	WSW 11	--	13	CLR	
	b)	-31.0	-35.1	67(91)	SSW 6	FIC	6.4	F 2	
	c)	-31.4	-35.6	66(90)	SSW 7	CLR	16	CLR	
0700	a)	-30.5	-35.8	66(81)	WSW 17	--	13	CLR	
	b)	-30.9	-34.9	68(92)	SW 6	FIC	3.2	F 3	
	c)	-33.8	-38.3	64(89)	S 7	--	16	CLR	
0800	a)	-30.3	-35.6	60(80)	SW 9	IF	24	F 1	
	b)	-30.8	-35.3	61(83)	SSW 6	FIC	1.6	F 3	
	c)	-32.8	-38.9	53(74)	S 7	--	16	Ci 1 (7.5)	
0900	a)	-30.4	-35.6	60(81)	WSW 15	--	13	CLR	
	b)	-30.7	-34.9	67(90)	SSW 6	IFIC	1.6	F 2	
	c)	-34.7	-38.6	68(96)	SSW 9	IC	24	Ci 1 (7.5)	
1000	a)	-28.7	-33.5	63(84)	WSW 11	--	24	CLR	
	b)	-29.8	-33.9	67(90)	SSW 6	IFIC	2.4	F 2	
	c)	-33.1	-37.1	67(93)	SSW 17	--	24	K 1 (0.05)	
1100	a)	-27.9	-32.8	63(82)	WSW 17	--	19	CLR	Tr
	b)	-26.3	-30.4	68(88)	SW 7	IC	16	CLR	Tr
	c)	-30.1	-34.2	67(90)	SW 13	--	24	K 1 (0.05)	Tr
1200	a)	-25.6	-30.3	65(82)	WSW 15	--	24	CLR	
	b)	-23.3	-26.9	72(94)	SW 6	--	19	Ci 1 (6.6)	
	c)	-26.7	-29.7	76(99)	S 9	--	24	K 1 (0.05)	
1300	a)	-23.1	-27.4	68(83)	WSW 7	--	24	CLR	
	b)	-22.9	-26.7	71(92)	SSW 6	--	19	Ci 1 (6.6)	
	c)	-25.4	-29.4	69(89)	SSW 11	--	24	Ci 1 (7.5)	
1400	a)	-23.0	-27.7	65(80)	SW 11	--	24	CLR	
	b)	-21.7	-26.7	64(79)	S 9	--	24	Ci 1 (6.6)	
	c)	-24.3	-28.2	70(90)	S 7	--	24	Ci 1 (7.5)	
1500	a)	-22.2	-27.2	63(76)	SW 11	--	24	CLR	
	b)	-20.9	-26.8	59(73)	S 7	--	24	Ci 1 (6.6)	
	c)	-24.4	-29.9	60(77)	SE 6	--	24	Ci 1 (7.5)	

Table D-2. February 1, 1978. Plant site and tower data.

Time (LST)	Celanese T (^{o}C)	Gulf wind (m/s)	CBC Tower 9 m T (^{o}C)	CBC Tower 91 m T (^{o}C)	CBC Tower γ (^{o}C/100 m)	CBC Tower 91 m wind (m/s)
0700		S 6.2	-28.9	-23.1	-7.07	W 8.9
0800	-34	S 6.2	-28.8	-23.1	-6.95	W 8.9
0900		S 6.2	-28.3	-22.0	-6.59	W 8.9
1000		S 5.3	-27.2	-23.4	-4.63	W 9.8
1100		S 5.3	-26.0	-22.9	-3.78	W 8.0
1200	-25	S 5.8	-24.4	-22.3	-2.56	W 8.0
1300		S 6.2	-23.3	-21.7	-1.95	W 6.3
1400		S 6.2	-22.2	-21.4	0.98	WSW 4.9
1500		S 6.2	-21.0	-20.8	0.24	WSW 5.4
1600	-22	S 5.8	-20.0	-20.0	0.00	W 3.6

Table D-3. February 1, 1978. Radiosonde soundings, Stony Plain.

Pressure (mb)	Height (m)	T (^{o}C)	γ (^{o}C/100 m)	T_d (^{o}C)	Mixing ratio (g/kg)	R.H. (ice) (%)	Moisture deficit (ice) (g/kg)	Wind (m/s)
0500 LST								
1000	262							
933	766	-30.7		-30.9	0.313	98 (134)	-0.006(+0.080)	W 7.7
			-6.31					
914	915	-21.3		-25.5	0.528	68 (86)	-0.239(-0.086)	
			-0.17					
857	1391	-20.5		-32.5	0.292	33 (41)	-0.585(-0.415)	
			-0.66					
850	1452	-20.1		-32.1	0.306	33 (41)	-0.609(-0.435)	NW 4.1
1700 LST								
1000	234							
930	766	-19.7		-27.7	0.424	49 (60)	-0.442(-0.280)	SW 3.6
			-2.01					
908	945	-16.1		-27.1	0.459	38 (45)	-0.745(-0.554)	
			0.00					
890	1096	-16.1		-34.1	0.241	20 (23)	-0.987(-0.793)	
			-1.42					
872	1251	-13.9		-32.8	0.279	19 (22)	-1.224(-1.014)	
			0.31					
850	1445	-14.5		-32.5	0.295	20 (23)	-1.174(-0.961)	SW 3.2

Table D-4. February 1, 1978. Minisonde soundings, Ellerslie.

Time (LST)	0920		1100		1340	
Height (m)	Temp (°C)	Wind (m/s)	Temp (°C)	Wind (m/s)	Temp (°C)	Wind (m/s)
0	-33.8	SSW 2.3	-27.5	SW 2.9	-23.7	SW 2.9
108	-26.2	SW 8.0	-22.0	WSW 5.9	-21.2	SSW 4.6
151	-	-	-18.0	-	-20.7	-
216	-20.0	WSW 11.2	-17.1	W 9.7	-17.3	W 6.6
275	-17.0	-	-	-	-	-
315	-16.7	W 10.5	-16.8	W 10.5	-16.1	WSW 8.6
414	-16.3	W 10.5	-15.7	W 8.6	-15.3	WSW 6.8
513	-16.0	W 9.2	-15.1	W 7.0	-15.4	WSW 4.9
612	-15.5	W 7.0	-15.0	WNW 5.7	-15.1	WSW 5.4
706	-15.2	WNW 7.1	-15.1	WNW 7.0	-14.1	W 5.9
763	-	-	-	-	-14.2	-
801	-15.0	W 13.4	-13.8	W 2.4	-13.3	WSW 5.8
895	-14.8	NNE 2.0	-14.0	W 4.4	-13.0	W 4.5
990	-14.3	WNW 7.0	-14.0	WNW 4.2	-12.8	W 3.9
1080	-14.0	WNW 5.3	-14.0	NW 3.8	-12.6	WNW 3.8

APPENDIX E

WEATHER DATA

January 9, 1980

Table E-1. January 9, 1980. Hourly observations.
a - YED, b - YXD, c - YEG

Time (LST)		T (^oC)	T_d (^oC)	R.H. (ice) (%)	Wind (km/h)	Weather & Vis. (km)	Cloud amt, 1/10s (base, km)	Pcpn
0700	a)	-34.0	-39.0	63(95)	WSW 4	IC 24	Ac 1 (3)	
	b)	-33.0	-37.1	67(100)	SW 6	IFIC 1.6	F 4	
	c)	-34.6	-39.0	67(100)	SSW 6	IFIC 10	Ac 1 (3.6)	
0800	a)	-34.0	-39.0	63(95)	WSW 7	IFIC 3.2	Ac 1 (3)	
	b)	-33.0	-37.1	67(100)	SSW 6	IFIC 1	F 5	
	c)	-34.9	-38.9	67(100)	Calm	IF 8	St (0.03)	
0900	a)	-35.0	-40.0	62(91)	WSW 4	IFIC 1.6	Ci 2 (7.5)	
	b)	-33.2	-37.1	67(98)	SSW 6	IFIC 1	Ci 1 (7.5)	
	c)	-36.8	-41.0	66(97)	Calm	IF 5	Ci 2 (7.5)	
1000	a)	-33.0	-38.0	62(91)	SW 11	IFIC 5	Ac 1 (3)	
	b)	-33.6	-34.7	67(98)	WSW 6	IFIC 1	Ci 1 (7.5)	
	c)	-35.0	-40.1	60(90)	Calm	IF 5	Ci 3 (7.5)	
1100	a)	-33.0	-38.0	62(91)	WSW 11	IFIC 3.2	Ac (3)	Tr
	b)	-33.0	-37.1	67(99)	SW 7	IFIC 1	Ci 1 (7.5)	Tr
	c)	-34.9	-38.2	74(103)	Calm	IFIC 5	K 1 (0.2)	Tr
1200	a)	-32.0	-37.0	62(91)	SW 7	IFIC 1.6	Ci 1 (7.5)	
	b)	-30.8	-36.0	61(90)	Calm	IFIC 1	F 4	
	c)	-31.7	-38.7	68(98)	Calm	IFIC 6.4	Ci 1 (7.5)	
1300	a)	-31.0	-36.0	61(89)	SW 7	IFIC 5	Ci 1 (7.5)	
	b)	-30.2	-34.4	68(100)	SSW 7	IFIC 1.2	Ci 1 (8)	
	c)	-31.6	-35.1	75(102)	WSW 4	IC 19	Ci 1 (7.5)	
1400	a)	-30.3	-35.0	61(88)	Calm	IC 16	Ci 1 (7.5)	
	b)	-28.7	-33.1	68(100)	Calm	IFIC 3.2	Ci 1 (8)	
	c)	-31.5	-35.8	68(100)	Calm	IC 13	Ci 1 (7.5)	
1500	a)	-29.0	-35.0	60(86)	Calm	-- 16	Ci 1 (7.5)	
	b)	-28.4	-32.6	62(90)	Calm	IFIC 6.4	Ci 1 (8)	
	c)	-31.2	-35.4	68(100)	NE 6	IC 19	Ci 1 (7.5)	

continued...

Table E-1, continued:

1600	a) -31.0	-37.0	59(86)	Calm	IF 5	Ci 1 (7.5)	
	b) -28.6	-32.4	75(103)	Calm	IFIC 1.6	Ci (8)	
	c) -31.9	-39.5	68(100)	Calm	IC 19	Ci 1 (7.5)	
1700	a) -31.0	-36.0	60(83)	Calm	IF 5	Ci 1 (7.5)	Tr
	b) -29.1	-33.2	68(96)	SW 6	IFIC 1.6	Ci 2 (8)	Tr
	c) -33.1	-38.1	61(89)	E 4	IC 19	Ac 1 (4.5)	Tr
1800	a) -30.3	-35.0	62(89)	Calm	IF 5	Ci 2 (7.5)	
	b) -29.8	-33.7	68(100)	SW 7	IFIC 1.2	F 5	
	c) -34.8	-38.6	67(100)	ESE 11	IC 19	Ac 1 (4.5)	

Table E-2. January 9, 1980. Plant site and tower data.

			CBC Tower			
Time (LST)	Celanese T (°C)	Gulf wind (m/s)	9 m T (°C)	91 m T (°C)	γ (°C/100 m)	91 m wind (m/s)
0700		S 1.4	-33.7	-28.9	-5.83	M
0800	-36	S 1.4	-33.6	-29.2	-5.35	M
0900		S 1.7	-33.5	-30.3	-4.27	M
1000		S 1.7	-33.5	-30.1	-4.20	M
1100		S 1.7	-31.8	-29.7	-2.56	M
1200	-30	S 2.2	-29.4	-29.4	0.07	M
1300		S 1.7	-29.4	-29.4	0.07	M
1400		S 2.2	-28.3	-28.9	0.75	M
1500		S 1.5	-27.4	-28.1	0.72	M
1600	-28	S 1.2	-28.2	-29.1	1.08	M
1700		S 0.8	-29.4	-29.4	0.00	M
1800		S 0.3	-30.1	-28.9	-1.42	M
1900		Calm	-30.9	-29.7	-1.56	M
2000	-34	S 0.3	-31.5	-29.1	-2.98	M

Table E-3. January 9, 1980. Radiosonde soundings, Stony Plain.

Pressure (mb)	Height (m)	T (^{o}C)	γ (^{o}C/100 m)	T_d (^{o}C)	Mixing ratio (g/kg)	R.H. (ice) (%)	Moisture deficit (ice) (g/kg)	Wind (m/s)
0500 LST								
1000	214							
925	766	-33.7	-5.66	-36.9	0.176	73 (103)	-0.066(+0.004)	W 2.6
918	819	-30.7	-0.96	-30.9	0.318	98 (134)	-0.006(+0.081)	W 2.6
894	1007	-28.9	-0.06	-28.9	0.395	100 (135)	0.0 (+0.101)	SW 1.5
850	1372	-28.7		-28.7	0.423	100 (134)	0.0 (+0.108)	SSE 2.6
1700 LST								
1000	139							
916	766	-29.7	-0.19	-32.8	0.266	74 (101)	-0.092(+0.002)	S 0.5
850	1279	-28.7		-31.7	0.318	75 (101)	-0.105(+0.003)	S 3.1

Table E-4. January 9, 1980. Minisonde soundings, Ellerslie.

Time (LST)	0900		1030		1200		1500	
Height (m)	Temp (°C)	Wind (m/s)	Temp (°C)	Wind (m/s)	Temp (°C)	Wind (m/s)	Temp (°C)	Wind (m/s)
0	-32.9	Calm	-32.6	Calm	-29.0	SW 0.5	-29.0	Calm
22	-32.9	-	-	-	-	-	-	-
86	-	-	-	-	-28.8	-	-30.0	-
108	-29.5	SSW 2.0	-28.8	SW 2.2	-27.4	SW 2.2	-29.5	SSE 2.2
216	-26.8	SW 3.8	-26.4	WSW 3.7	-24.7	WSW 3.8	-27.4	SSW 0.6
315	-25.8	SSW 4.7	-25.9	WSW 4.2	-24.0	WSW 3.4	-27.0	SSW 1.1
415	-25.4	SSW 3.8	-25.2	WSW 4.6	-23.7	WSW 3.7	-27.1	S 2.2
513	-25.3	SSW 3.0	-25.1	SSW 3.1	-23.2	SW 2.8	-27.1	S 2.7
612	-25.3	SSE 0.9	-24.9	S 1.7	-22.7	SSE 3.2	-27.0	SSE 2.9
706	-24.8	SSW 2.8	-24.4	SE 1.6	-22.5	SSE 3.0	-27.1	SSE 2.7
801	-24.9	SSW 2.4	-24.4	SSW 1.8	-22.6	S 1.8	-27.3	SSE 3.5
895	-24.4	SSE 2.6	-24.4	SSE 2.0	-22.7	SE 2.8	-27.3	S 3.8
990	-24.5	SSE 3.4	-24.4	SE 3.9	-23.0	SSE 4.5	-27.3	S 4.1
1080	-24.5	S 5.1	-24.9	SSE 4.3	-23.1	S 4.7	-27.2	S 4.8

APPENDIX F

Table F-1. Summary of all days.

Temp Range °C	Field times	Sfc temp °C	Sfc wind m/s	91 m temp °C	91 m wind m/s	Low Lvl R.H.	Sky cond	Industrial Observations: Vis (km)	Weather	Samples
-15 to -20										
Feb 2/78	0900-1130	-19	S5.6	-19	S12.6	<ice	CLR	14		
Feb 4/78	0830-1100	-18	SE4.4	-18	S9.7	<ice	CLR	13		
Feb 11/78	0830-1100	-19	E1.5	-21	SE7.9	<ice	CLR	13		
Feb 14/78	0830-1100	-18	S1.8	-17	S7.1	<ice	CLR	12		
Feb 15/78	0800-1100	-19	SSE1.8	-16	S3.7	>ice	CLR	7	IC,S--	replica, trays
Feb 16/78	0800-1130	-17	SE2.7	-12	W5.5	<ice	SCT	9		
Feb 17/78	0900-1100	-12	S3.1	-14	WSW6.7	<ice	CLR	9		
Mar 1/78	0700-1130	-19	Calm	-16	SSE1.1	<ice	CLR	8(<0.2)	,SW	replica, trays
Mar 3/78	0900-1100	-18	S5.8	-19	SSE11.6	<ice	CLR	11		
Mar 4/78	0800-1100	-17	S1.6	-18	NW4.2	=ice	CLR	10	IC,SW--	replica
-20 to -25										
Jan 18/78	0830-1030	-21	SE4.1	-18	SSE11.1	<ice	CLR	14		
Feb 3/78	2100-2300	-23	SE2.0	-21	SE3.8	<ice	CLR	8		
Feb 28/78	0800-1130	-21	S2.6	-19	SSW2.2	=ice	CLR	6(≃2)	IC,S--	replica, trays
Dec 28/78	0900-1230	-24	SW2.4	-24	NW3.5	=ice	CLR	6(≃2)	IC,S--	replica, trays
Dec 31/78	0900-1100	-21	W8.9	-21	S12.1	<ice	CLR	14		
Jan 2/79	0830-1230	-23	W3.1	-23	WNW3.1	=ice	CLR	5(<0.3)	IC,IF,SW-	replica, trays
Jan 4/79	0930-1130	-22	S3.1	-21	WNW4.9	<ice	CLR	12		
-25 to -30										
Dec 4/77	1000-1200	-28	W5.8	-28	NW10.1	<ice	CLR	10		
Jan 29/78	0900-1100	-27	S4.4	-26	W4.8	=ice	CLR	5	IC,IF,S--	
Jan 31/78	0830-1500	-27	SSW3.1	-25	WNW2.9	=ice	CLR	5(≃1.0)	IC,IF,S-	
Feb 1/78	0800-1000	-29	S5.8	-23	W8.9	<ice	CLR	6	IC,IF	

continued ...

Table F-1, continued:

-25 to -30										
Dec 29/78	0800-1230	-26	S3.8	-25	WNW3.6	>ice	CLR	5	IC,IF,S--	replica, trays
Jan 12/79	0830-1200	-26	S1.6	-26	N3.1	=ice	CLR	4	IC,IF,S--	
Jan 13/79	0830-1100	-28	S2.1	-30	W4.0	>ice	CLR	4	IC,IF,S--	replica, trays
Jan 14/79	0830-1300	-27	S2.0	-20	SSW1.0	<ice	CLR	4	IC,IF,SW-	replica, trays
Feb 8/79	0900-1100	-29	NE2.6	-30	SE4.4	=ice	CLR	5	IC,IF	
Feb 17/79	0830-1400	-27	Calm	-25	SSW2.1	>ice	CLR	4(<0.1)	IC,IF,SW	replica, trays
Jan 7/80	0900-1100	-28	WNW5.2	-27	SSE7.8	<ice	CLR	6		
Jan 29/80	0830-1030	-27	S4.7	-27	S6.2	<ice	CLR	6		
-30 to -35										
Dec 5/77	0830-1100	-31	N3.5	-32	N4.0	>ice	CLR	4	IC,IF,S--	
Dec 8/77	0930-1200	-33	NE1.7	-35	N1.1	>ice	CLR	2	IC,IF,S--	
Dec 30/78	0830-1030	-31	SW4.3	-32	NW4.5	>ice	CLR	4	IC,IF,S--	
Feb 15/79	0830-1120	-33	SSE8.0	-31	SSE9.0	<ice	CLR	6	IC,IF(brief)	
Feb 16/79	0830-1030	-31	SE3.6	-32	SE3.9	>ice	SCT	4	IC,IF,S--	
Jan 9/80	0830-1100	-33	S2.2	-29	SW2.6	>ice	CLR	1(<<0.1)	IC,IF,S-	
	1500-1800	-28	Calm	-29	SSW1.7	>ice	CLR	3(<0.5)	IC,IF,S-	replica, trays
-35 to -40										
Dec 9/77	0800-1000	-39	SE1.5	-34	S4.2	>ice	CLR	1.5(<<0.1)	IC,IF	